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CONTENTS

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Articles for December *Bulletin*

STRATIGRAPHY OF PERMIAN IN OKLAHOMA AND KANSAS

Editorial Note
By Robert H. Dott

Major Divisions of Permian in Oklahoma and Kansas
By Darsie A. Green

Discussion: Quartermaster Unconformity of Weatherford Area, Oklahoma
By Noel Evans

Unconformity at Base of Whitehorse Formation, Oklahoma
By Otto E. Brown

Discussion
By Henry Schweer and Hastings Moore

Lower Red-Beds of Kansas (Abstract)
By George H. Norton

Permian Conference at Norman, Oklahoma
Edited by Robert H. Dott

Volume 21 Number 11

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NOVEMBER, 1937

STUDIES OF SOURCE BEDS IN OKLAHOMA AND KANSAS[1]

PARKER D. TRASK[2]
Washington, D. C.

ABSTRACT

Some of the eight properties of sediments from different parts of the United States that have been investigated as a possible means of recognizing source beds of petroleum appear to be of value in the recognition of source rocks in Oklahoma and Kansas. As a basis for study, sediments near oil zones have been assumed in general to be relatively rich in source material in comparison with those far from oil zones. For the purpose of averaging out the effect of anomalies caused by exceptions to this generalization, an unusually large number of samples—many thousands of samples—from many areas in the United States have been analyzed. The four properties named below were observed to be approximately the same in sediments near and far from oil zones, and hence seem to be of little value as indices of source beds: (1) the total quantity of organic matter in the sediments; (2) the color of the sediments; (3) the reducing power, which is a measure of the quantity of chromic acid the sediment can reduce; and (4) the oxidation factor, which is a measure of the state of oxidation of sediments, and specifically is the ratio of the carbon content to the reducing power of the sediments. The three following properties were noted to be slightly greater in sediments near oil zones than in those far from oil zones, and therefore apparently offer fair promise as indices of source beds: (1) the ratio of carbon to nitrogen in the sediments; (2) the quantity of volatile materials; and (3) the degree of volatility, which is a measure of the relative volatility of the organic constituents of sediments and specifically is the ratio of the volatility to the reducing power. The eighth property, the nitrogen-reduction ratio, which is the ratio of the nitrogen content to the reducing power, was found to be distinctly lower in sediments near oil zones than far from oil zones, and consequently seems to be particularly encouraging in the study of source beds. In fact, in several oil areas in Oklahoma and Kansas it seems to be 65 to 75 per cent effective as a means of recognizing source beds.

INTRODUCTION

The United States Geological Survey and the American Petroleum Institute have sponsored jointly for several years an investigation of

[1] Published by permission of the director, United States Geological Survey. Paper presented in part before the Association at Tulsa, March 21, 1936. Manuscript received, September 9, 1937.

[2] United States Geological Survey.

source beds of petroleum. The main objective of the investigation has been to develop criteria for recognizing source beds. The term source beds is here applied to ancient (lithified) sediments that either already have generated oil or are still capable of generating oil. If the sediments have already yielded oil they possibly may have exhausted their capacity to form oil, and the substances they now contain may have little to do with the origin of oil. The substances still remaining in such sediments may, however, possess distinctive characteristics that will indicate that the sediments containing them were once capable of generating oil.

The ideal way to approach the problem of source beds would be to investigate sediments that are definitely known to be source beds, in order to determine the differences between them and non-source beds. In that way distinctive criteria could be ascertained for recognizing oil-making beds. Unfortunately few if any sediments are definitely known to be source beds. The problem accordingly has to be approached by inference, and an assumption has to be made as to what types of sediments are source beds.

One such assumption is that oil in general accumulates relatively near its place of generation. A recent paper interprets the results of several thousand analyses on the basis of this assumption.[3] Eight properties of sediments were investigated for significant differences between sediments near oil zones and sediments far from oil zones. One of the eight properties, the nitrogen-reduction ratio (described below), was observed in general to be low in sediments near oil zones and high in sediments far from oil zones. This property therefore seems to offer promise of being useful in the recognition of source beds. The object of the present paper is to discuss this ratio further, especially for areas of Oklahoma and Kansas.

Because the paper just cited does not have a wide circulation among readers of the *Bulletin*, a summary of its main features is given here. The illustrations in the present paper are taken from the previous article.

The chemical analyses that form the basis for the present paper were made by H. E. Hammar, R. W. Gillespie, R. V. Hughes, J. L. Stimson—all employees of the American Petroleum Institute—and the writer. Acknowledgment is due H. W. Patnode, also employed by the American Petroleum Institute, for assistance in compiling the data. The analyses were made in the laboratory of the Division of Chemistry of the National Bureau of Standards, Washington, D. C.

[3] Parker D. Trask and H. Whitman Patnode, "Means of Recognizing Source Beds," *Drilling and Production Practice, 1936*, Amer. Petrol. Inst. (1937), pp. 368–83.

The preparation of the paper has been facilitated materially by discussions with several geologists, particularly Frederic A. Bush, K. C. Heald, Thomas A. Hendricks, J. B. Leiser, Alex. W. McCoy, H. D. Miser, Robert J. Riggs, Walter B. Wilson, and Fred E. Wood.

THE BASIC ASSUMPTION

This study of source beds rests, as previously stated, on the assumption that oil more commonly migrates a short distance than a long distance. Movement of oil across the bedding (vertical migration) in general is more difficult than movement more or less parallel to the bedding (lateral migration). Unless fissures or faults are present that facilitate the movement of the oil, it is hard to understand how oil ordinarily can move many hundreds of feet across the bedding. The presence of water sands between oil sands in many fields is presumptive evidence against great stratigraphic migration, because it is difficult to conceive of how oil could have passed through intermediate water zones without being trapped.

Petroleum, however, can migrate for a considerable distance laterally parallel with the bedding, especially if the sediments are sandy. Structural irregularities and variations in permeability of the strata would interfere with its movement; and, geologic conditions being such as they are, it seems unlikely that oil could move far without being trapped or escaping to the surface of the ground. Some of the oil in certain fields, such as the East Texas field, undoubtedly has come a long distance, but if a large number of fields are considered, it seems probable that in most of them, that is, in considerably more than one-half, it has migrated a few miles rather than tens of miles.

STATISTICAL BASIS FOR STUDIES

If the foregoing assumption about migration is made, the problem lends itself to a statistical treatment based on the laws of probability, because any existing relationship should be indicated by the averages of results from a large enough number of units, provided the relationship is not masked by factors that are not considered. If the nitrogen-reduction ratio is found on the average to differ in sediments near oil zones from the ratio in sediments far from oil zones, the presumption will arise that this property is a characteristic that bears some relation to source beds. If such a difference is noted, it is then necessary to ascertain whether the observed difference is real or anomalous.

The question of the significance of a difference is treated in detail in textbooks of statistics,[4] and, as applied to the problem of source

[4] R. E. Chaddock, *Principles and Methods of Statistics*, Houghton Mifflin Co., New York (1925), p. 243.

beds, has been discussed in a previous publication.[5] To ascertain the reliability of an observed difference, the probable error of the difference must be known. The probable error of a difference is a measure of the unreliability of the difference and it varies inversely with the number of units involved; the greater the number of units, the smaller is the probable error.[6] In order for a difference to be significant, it should be at least four times greater than the probable error; that is, the quotient of the difference and its probable error should be at least 4.0. Quotients between 4.0 and 1.0 indicate increasingly smaller degrees of probability that the difference is real, and quotients less than 1.0 indicate that the observed difference probably is not real. Thus in Figure 1, where the quotients indicated by D/P.E. in the last column are less than 1.0, the observed differences are of little significance; but in Figure 8, where all five of the quotients are greater than 4.0, the differences between the "productive" and "barren" sediments in all the areas studied are probably real differences.

The distinctiveness of the difference between the "productive" and "barren" sediments, indicated by Figure 8, demonstrates that the sediments in the "productive" class have in general a lower nitrogen-reduction ratio than the sediments in the "barren" class. Though the generalization seems indicated by the statistical data, the inference does not follow that all sediments near oil zones have lower ratios than sediments far from oil zones. In fact, numerous exceptions to the generalizations exist, but these exceptions are few in comparison with the instances in which the generalization holds. Consequently, it is not yet possible to work backwards and infer that an individual sediment having a low nitrogen-reduction ratio is probably a source bed. On the contrary, that particular sediment might be one of the exceptions; but if 25 such sediments were found to have a low ratio, the presumption follows that the majority of them probably are relatively rich in source material.

The best way to evaluate the true nature of a relationship is to consider a large number of units distributed over a great variety of conditions. If an observed relationship holds in a similar way throughout each of several different series of conditions and continues to do so as each new series of conditions is studied, as has the nitrogen-reduction ratio thus far, the presumption is strong that it is a real relationship.

In the appraisal of the relative value of the eight properties of sediments as possible means of recognizing source beds, the number

[5] Parker D. Trask and H. Whitman Patnode, *op. cit.*, pp. 372–73.

[6] R. E. Chaddock, *op. cit.*, pp. 206–47.

of analyses that have been considered ranges from 2,300 for the carbon content to 23,000 for the volatility. These analyses of sediments from many different parts of the United States are sufficiently large in number for them to indicate fairly well the relative value of the different properties of the sediments with respect to the usefulness of the properties as a means of recognizing source beds.

LIMITS USED IN CLASSIFYING SEDIMENTS AS APPARENT SOURCE BEDS

The question arises as to what criteria of nearness should be used for segregating good from poor source beds. A single arbitrary distance can not very well be set up, because of the varying conditions of migration and accumulation in different fields; yet the same standards should be applied for classifying the sediments in all areas studied. A three-fold scheme of classification seems better than a two-fold one. If a dual classification is used, an arbitrary line of separation has to be made between the class of sediments regarded as good source beds and the class considered as poor source beds; whereas, if a three-fold classification is adopted, a broad intermediate class can be set up between the other two classes. The limits of this intermediate class can be made sufficiently wide to counterbalance to a considerable extent the effect of the uncertainty of distance of migration. The limits of the first class can be placed so close to oil zones that the probabilities are very strong that the sediments in it are rich in source material; and the limits of the third class can be put so far from oil zones that the sediments in it are reasonably certain to be poor in source material. The second class, between the other two classes, would consist of sediments of questionable ability as source beds.

In making this three-fold classification an attempt has been made to set up arbitrary units of distance, but it was not practicable to follow these limits absolutely, because sediments differ in lithology and because the geologic conditions in certain areas make it desirable to vary the limits for some beds.

The first class includes sediments less than 2 miles from an oil field, and within 250 feet stratigraphically above and below an oil zone.

The second class includes (1) sediments lying less than 2 miles from an oil field, and between 250 and 500 feet stratigraphically above or below an oil zone, (2) sediments between 2 and 15 miles distant from an oil field, and within 500 feet stratigraphically above or below an oil zone, (3) sediments more than 15 miles distant from an oil field in areas in which that particular zone is generally productive, and within 250 feet stratigraphically of an oil zone, and (4) sediments

less than 250 feet above or below an oil zone whose sediments yield significant quantities of oily substances when extracted with ether.

The third class includes all other sediments, namely sediments more than 15 miles distant from an oil field and those 500 feet stratigraphically above or below an oil zone. This class does not include the sediments that are situated less than 250 feet above or below a zone that usually yields oil in the general region or whose sediments contain significant quantities of oily substances soluble in ether. The three classes are referred to in this paper as "productive," "questionably productive," and "barren," respectively.

In making this classification, the sediments were grouped into lithologic or formational units, which range in thickness from 50 to 500 feet. From 2 to 20 analyses have been made on the sediments from each unit. Approximately 850 such units are used and they are divided about equally into each of the three classes of sediments. They come from five petroliferous provinces—California, Rocky Mountains, Mid-Continent, East Texas basin, and Gulf Coast. Each province is represented by 10 to 50 areas from which samples have been obtained.

The geological conditions under which oil is found vary in these different provinces and the results are presented in terms of averages for each province rather than as general averages for all the provinces. If the general average were given, a large difference in one area might dominate the entire relationship, as for example the oxidation factor in Figure 7. This factor in the Rocky Mountain and East Texas region shows no consistent difference for "productive" and "barren" beds, whereas it does exhibit a large difference in the Mid-Continent area.

PROPERTIES STUDIED

Eight properties or characteristics of sediments have been considered. These are (1) carbon content, (2) color, (3) reducing power, (4) volatility, (5) degree of volatility, (6) carbon-nitrogen ratio, (7) oxidation factor, and (8) nitrogen-reduction ratio. They are all relatively simple properties that are determinable within a short time and with fair reliability. Only a short description of them is given here; they have been described in detail in previous publications.[7]

Carbon content.—The determination of the carbon content C is the most reliable means for ascertaining the quantity of organic matter

[7] P. D. Trask and H. E. Hammar, "Organic Content of Sediments," *Drilling and Production Practice, 1934*, Amer. Petrol. Inst. (1935), pp. 117–130.

———, "Degree of Reduction and Volatility as Indices of Source Beds," *Drilling and Production Practice, 1935*, Amer. Petrol. Inst. (1936), pp. 250–66.

P. D. Trask and H. Whitman Patnode, "Means of Recognizing Source Beds," *Drilling and Production Practice, 1936* (1937), pp. 368–83.

in the sediments. The average carbon content of the organic constituents of ancient (lithified) sediments is roughly 64 per cent. The range, however, seems to be mainly between 56 and 71 per cent.[8] The organic content, therefore, can be roughly considered as being 100/64 or 1.6 times the carbon content. The carbon content (carbonates not being considered) is determined by wet combustion, with potassium permanganate and sulphuric acid as oxidizing agents. The carbon content is the most difficult of all the properties to determine with desired accuracy and the method of analysis is more time-consuming. Carbon has been determined on about 2,300 samples, which come mainly from the Rocky Mountains, Mid-Continent, and East Texas basin.

Color.—Color has been regarded by many geologists as a guide in recognizing source beds,[9] presumably because it has been considered to be an index of the organic content of sediments. Dark sediments have been believed to be rich in organic matter and light sediments, poor. The color of 1,000 finely ground samples distributed more or less representatively over the regions that were studied has been matched against a series of standard colors, for the purpose of determining the relationships of color to organic content and also to the ability of the sediments to generate oil.

The essential thing measured was the intensity of the colors. Difficulty was encountered, however, in matching the intensity, because of difference in hue. The main hues observed were gray, brown, green, yellow, red, maroon, bluish gray, and olive brown. Several grades of intensity from light to dark were selected for each of these hues. At first a dozen color standards were regarded as sufficient, but ultimately 37 were found necessary.

After the color standards had been selected, some trouble was encountered in arranging them in order of increasing intensity, owing to the difficulty of appraising similar intensities for sediments of different hue. Sediments colored red and yellow with iron oxide were particularly difficult to place in their proper position with respect to sediments of other hues. Several independent arrangements of intensity were made and as they were found to agree rather closely, an average was taken for the arrangement finally chosen. A photograph of these standards taken with panchromatic film showed a fairly uniform increase in intensity for the suite of standards.

[8] P. D. Trask, "Inferences about the Origin of Oil as Indicated by the Composition of the Organic Constituents of Sediments," *U. S. Geol. Survey Prof. Paper 186-H* (1937), p. 153.

[9] L. C. Snider, "Current Ideas Regarding Source Beds of Petroleum," *Problems of Petroleum Geology,* Amer. Assoc. Petrol. Geol., Tulsa (1934), pp. 51–66.

Reducing power.—Sediments have the ability to reduce substances such as chromic acid. In this process of reduction, oxygen is removed from the chromic acid and added to the constituents of the sediments. The number of cubic centimeters of 0.4 N chromic acid that can be reduced by 100 milligrams of sediment has arbitrarily been taken as a measure of the reducing power, *R*, of a sediment. The chromic acid is reduced both by organic and inorganic constituents of the sediments, but ordinarily most of the chromic acid that is reduced seems to be reduced by the organic constituents. In fact, the reducing power, though subject to some variation, has been found to be a rough index of the organic content of the sediment. The reducing power is determined much more rapidly than the carbon content and individual determinations have a greater reliability. The reducing power has been determined on 7,000 samples from many different places in the United States.

Volatility.—The organic constituents of sediments contain volatile substances. A measure of the quantity of these volatile materials can be obtained by distilling a small quantity of the sediment in a narrow test tube. Tarry and oily substances accumulate on the upper walls of the tubes, and the quantity of such substances is estimated by comparison with known standards. Unit numbers are used to designate the amount of distillate, except below 3, where fractional units are used. These numbers are called "assay" numbers and are designated by the symbol *A*. Individual determinations are made with considerable rapidity and they can be readily duplicated. However, as not all the volatile materials collect on the walls of the tubes, the method affords only a rough determination of the volatility. The volatility has been measured on 23,000 samples from different areas in the United States.

Degree of volatility.—The volatility varies more or less directly with the organic content. Sediments that contain little organic matter generally have low assay numbers, and those that contain much organic matter generally have high numbers. However, the organic constituents of sediments vary in the quantity of volatile material they contain. In order to measure this volatility relative to the total quantity of organic substances in a given sediment, the assay number is divided by a measure of the organic content. For example, if two sediments have assay numbers of 4, but one contains 2 per cent organic matter and the other contains 4 per cent, the volatility relative to the organic content of the first is 4/2, or 2, and of the second 4/4, or 1. The relative volatility of the first, therefore, is double that of the second.

The ratio of the assay number to the carbon content, A/C would be the most reliable index of the degree of volatility to use; but, as carbon has not been determined on as many samples as the reducing power, which is also a measure of the organic content, the ratio of the assay number to the reducing power, A/R, has been used in this report.

The degree of volatility can not be determined with desired reliability in sediments that contain very small quantities of organic matter, such as the sediments in the Gulf Coast area. In this area many sediments have the lowest possible assay number of 0.2, yet their reducing power ranges from 0.02 to 0.2. The degree of volatility, which is the assay number divided by the reducing power, accordingly ranges from 10 to 1. However, if a more sensitive measure of the volatility were available, the assay number of some of the sediments would probably be less than 0.2, hence the sediments would have a lower coefficient of volatility than indicated by present means of measurement.

Carbon-nitrogen ratio.—The carbon-nitrogen ratio, C/N, is an index of the proportion of nitrogen in the organic matter. If the ratio is high, the proportion of nitrogen is small; and if the ratio is small, the proportion of nitrogen is large, provided the proportion of carbon in the organic matter is constant. For example, if the carbon content of two sediments is 1.0 per cent, and the nitrogen content of one is 0.05 per cent and of the other 0.07 per cent, the carbon-nitrogen ratios are 1.0/0.05, or 20, and 1.0/0.07, or 14, respectively. Because the carbon-nitrogen ratio in many sequences of sediments varies only slightly, the percentage of nitrogen in those sediments serves as a rough index of the organic content. The general size of the ratio, however, is appreciably different in different areas, and the variations are sufficiently significant to warrant their study in connection with the problem of source beds.

Oxidation factor.—The oxidation factor, C/R, is the ratio of the carbon content of the sediments to the reducing power. It is a crude index of the oxygen content of the organic constituents of sediments, but it is more appropriately a measure of the degree of reduction of the sediments. Sediments that have low oxidation factors can reduce relatively large quantities of chromic acid. For example, if two sediments have an organic carbon content of 1.0 per cent, but one reduces 1.25 units of chromic acid and the other reduces only 1.00 unit, the first is stronger in reducing power per unit of carbon than is the second. Its oxidation factor is 1.0/1.25 or 0.80 compared with 1.0/1.0 or 1.00 for the second. The first sediment, which is in a state of greater

reduction than the second, has a lower oxidation factor, but since it has a greater degree of reduction, it contains proportionately less oxygen than the second—at least with respect to the constituents that are affected by chromic acid. Thus low oxidation factors indicate relatively low contents of oxygen in the organic and other constituents, that is, a low degree of oxidation; or since oxidation and reduction are antithetical properties, low oxidation factors indicate a high degree of reduction. The oxidation factor ranges mainly between 0.70 and 1.20. The general average is approximately 0.9.

Nitrogen-reduction ratio.—The nitrogen-reduction ratio, N/R, is the ratio of the nitrogen content to the reducing power. Because the units used for measuring the nitrogen content are so much smaller than those used for indicating the reducing power, the form of the ratio ordinarily used is 100 times the percentage of nitrogen divided by the reducing power. The nitrogen-reduction ratio is similar to the oxidation factor, C/R, except that nitrogen has been substituted for carbon for indicating the organic content of the sediments. Like the oxidation factor, the ratio is a more or less crude index of the state of oxidation of the sediment—a low ratio indicates a relatively low state of oxidation, and a high ratio, a relatively high state. Moreover, as nitrogen seems to be related to source beds, the presence of nitrogen in the ratio makes this ratio desirable to study on its own merits, aside from its relation to the state of oxidation. An especially advantageous feature of the ratio is the ease and rapidity with which it may be determined compared with some of the other properties of sediments discussed in this report. The ratio has been determined on about 5,000 samples from different areas in the United States.

RESULTS

Charts have been prepared which indicate the average magnitude of each of the properties of sediments for each of the three classes of productivity—"productive," "questionably productive," and "barren," for each of the petroliferous provinces for which data are available (Figs. 1–8). The data are presented in the form of black blocks, the heights of which indicate the average magnitude of the particular property for the category represented. Numbers above the blocks give the numerical value of these averages. The difference between the averages for the "productive" and "barren" beds and the probable error of this difference are presented on the right side of the figures. The quotient of the difference and its probable error is indicated in the last column.

Carbon content.—The carbon content is not particularly different

for the "productive" and "barren" beds in each of the three regions for which data are available (Fig. 1). The average quantity of carbon in the sediments, however, differs in the different regions. In the Rocky Mountain region it is about 1.5 per cent; in the Mid-Continent, 0.65, and in the East Texas basin, 0.87 per cent. The general average for these three regions is slightly less than 1.0 per cent. As the organic content is roughly 1.6 times the carbon content, the average quantity

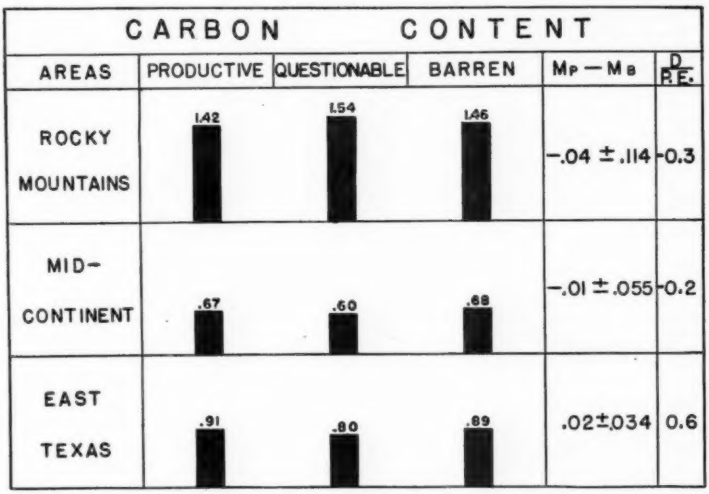

FIG. 1.—Relation of carbon content to productivity of sediments. The three classes of productivity: "productive," "questionable" (or "questionably productive"), and "barren," represent the classification of the sediments as to favorable, questionably favorable, and poor source beds, respectively. Numbers above black blocks indicate average (median) percentage of carbon for the individual grades of productivity. Height of blocks is proportional to the numbers above the blocks. $M_P - M_B$ represents the difference between the averages for the "productive" and "barren" sediments, together with the probable error of the difference. D/P.E. indicates quotient of difference and its probable error.

of organic matter in the formations studied from these three regions is 2.5 per cent for the Rocky Mountains, 1.0 per cent for the Mid-Continent, and 1.4 per cent for the east Texas basin. The general average for the three areas is about 1.5 per cent.

The carbon content is essentially the same for the "productive" and "barren" classes of sediments. The conclusion therefore seems evident that quantity of the carbon is not a dominant characteristic of source beds. Sediments that contain little organic matter are about

equally divided between areas close to oil zones and areas far from oil zones, and the same relationship seems to apply for sediments of intermediate and high organic contents. The quantity of organic matter is, however, of necessity a factor in the generation of oil, for a smaller volume of sediment rich in organic matter would ordinarily be needed to form a commercial pool than if the sediment were poor in organic matter.

Color.—Color of the sediments was found to vary more or less directly with the organic content (Fig. 2). Light sediments ordinarily

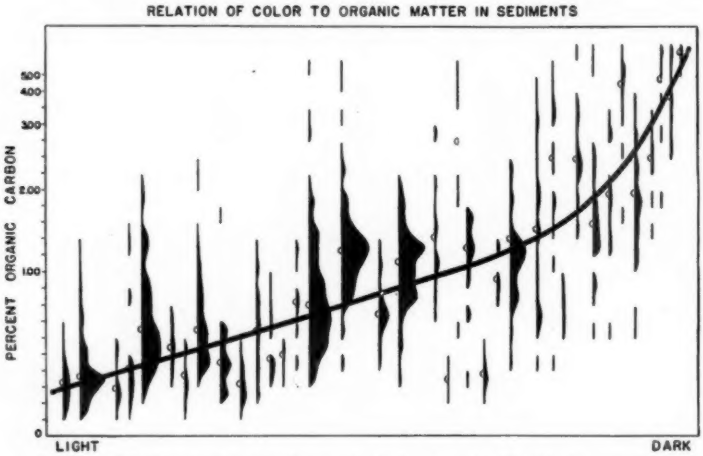

FIG. 2.—Relation of color to carbon content of sediments. The black areas show the variation in carbon content of each of 37 different color classes of sediments, arranged in order of increasing darkness. In these individual black areas, the ordinates represent percentage of carbon in the sediments; the abscissas indicate the relative frequency of sediments of given organic content for the particular color represented by the black area. For example, for the color represented by the second black area from the left, a large part of the sediments has a carbon content of about 0.3 per cent, but the total range in carbon is from 0.1 to 1.2 per cent. The half circles indicate averages (medians) of the carbon content of the individual color groups. The heavy black line shows the general trend that is indicated by the averages.

contain little organic matter and dark sediments generally contain much. Insufficient analyses have been made to warrant the preparation of a chart showing the relation of color to the three classes of productivity, but a chart showing the relation of color to organic content has been made. This chart indicates rather clearly that the organic content increases as the color becomes darker, though the sediments of the same color show some variation in organic content. As the color seems to vary with the organic content, it probably is of

the same negligible value in the recognition of source beds as is the organic content.

In Figure 2 the samples are arranged according to 37 classes of color, which are arranged in order of increasing darkness. All the samples for each individual color are plotted as individual black areas according to the carbon content. The larger the size of the black areas, the greater is the number of samples for that particular color. The carbon content is plotted on a scale that roughly approximates a

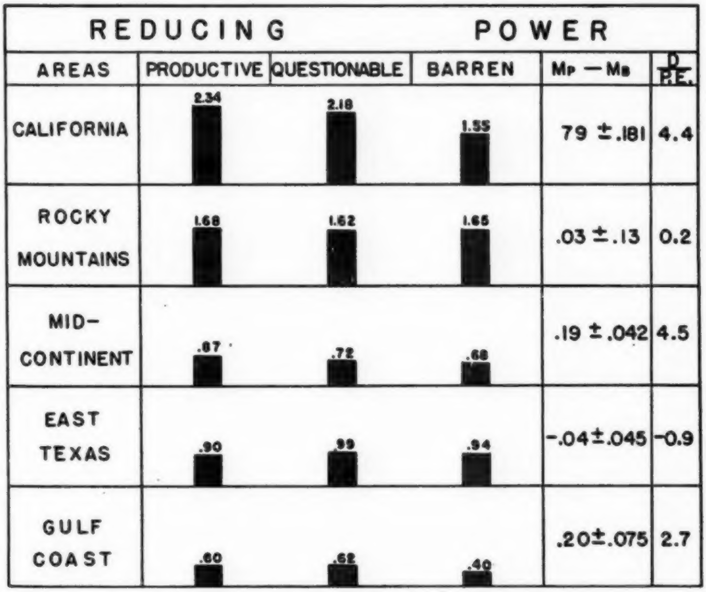

FIG. 3.—Relation of reducing power to productivity of sediments. Figures above blocks represent average reducing power for the individual grades of productivity. See Figure 1 for explanation.

logarithmic scale, because the proportionate increase in carbon content is more pertinent with respect to color than actual increases. For example, a rise in carbon content from 0.4 to 0.5 per cent is a gain of 25 per cent in quantity of organic matter, whereas a rise of 4.0 to 4.1 per cent, though equal numerically to the increase in the example above, represents a gain of only 2.5 per cent in the organic content. Sediments colored red and yellow with iron oxide contain less organic matter than other sediments that have colors of similar intensity, as

is indicated by the three color groups whose relatively low medians are in the lower right part of Figure 2. These three color groups represent iron-stained sediments.

Reducing power.—The average reducing power is essentially the same for "productive" and "barren" sediments in the Rocky Mountain, East Texas, and Gulf Coast regions, but in the Mid-Continent and California it is considerably higher for the "productive" than for the "barren" units (Fig. 3). Because of this variability in distinctive-

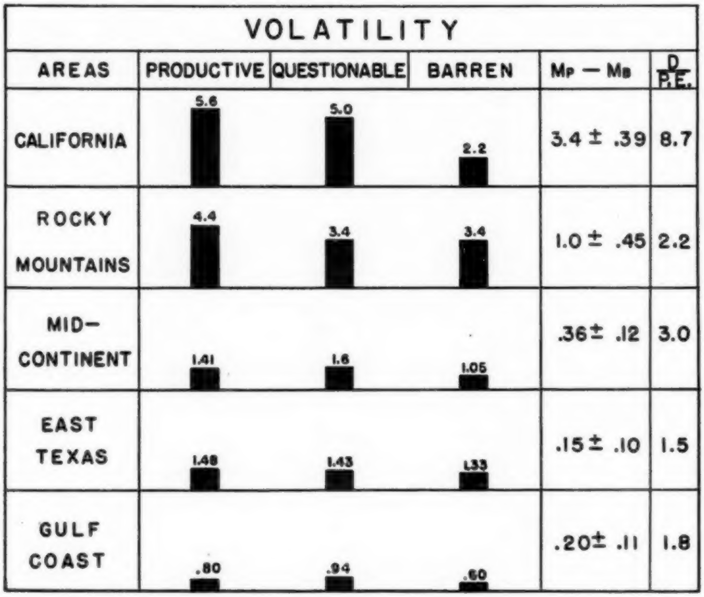

FIG. 4.—Relation of volatility to productivity. Numbers above blocks indicate average assay numbers. See Figure 1 for explanation.

ness for the different regions, the reducing power offers only slight encouragement as a means of recognizing source beds. Like the organic content, it varies in the different regions. The average is more than 2.0 units in California, about 1.6 in the Rocky Mountains, 0.95 in East Texas, 0.75 in the Mid-Continent, and 0.5 unit in the Gulf Coast. As each unit is roughly equivalent to one per cent carbon in the sediments, these figures indicate that the carbon content of the California and Gulf Coast sediments is approximately 2.0 and 0.5 per

cent respectively. The organic content, being about 1.6 times the carbon content, accordingly would be 3.2 per cent for the California sediments and 0.8 per cent for the Gulf Coast sediments. The low content of the Gulf Coast sediments appears to indicate the small proportion of organic matter that is needed to produce a commercial oil field in some areas.

Volatility.—The volatility for the "productive" sediments is greater than for the "barren" sediments in each of the five regions

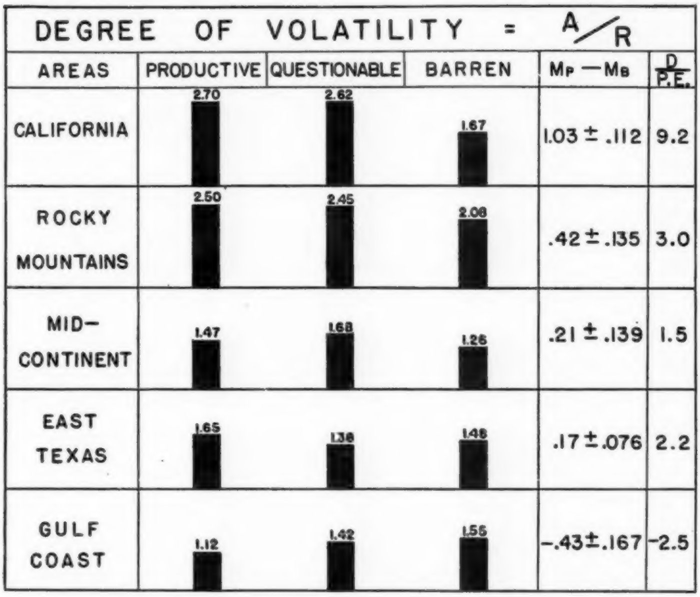

FIG. 5.—Relation of degree of volatility to productivity. The degree of volatility, *A/R*, is the ratio of the assay number, *A*, to the reducing power, *R*. Numbers above blocks represent average degree of volatility. See Figure 1 for explanation.

studied (Fig. 4), but in three of the regions it is only slightly greater. The California area is the only one in which it is distinctly greater for the "productive" than for the "barren" beds. In this region the average of the "productive" sediments is 5.6 compared with 2.2 for the "barren." In the Gulf Coast the average volatility is less than 1.0, in the East Texas basin and the Mid-Continent it is about 1.4, in the Rocky Mountains and in California it is about 4.0. The volatility,

because of this variability from region to region, offers only fair promise as a means of recognizing source beds.

Degree of volatility.—The degree of volatility varies less from region to region than the volatility and hence appears to be of value in recognizing source beds (Fig. 5). California, however, is the only area in which the degree of volatility is distinctly greater for the "productive" than for the "barren" beds. In the other regions the difference between the "productive" and "barren" areas is not sufficiently greater than the probable error to be distinctive. Moreover, in the Gulf Coast region the degree of volatility in the "barren" beds is

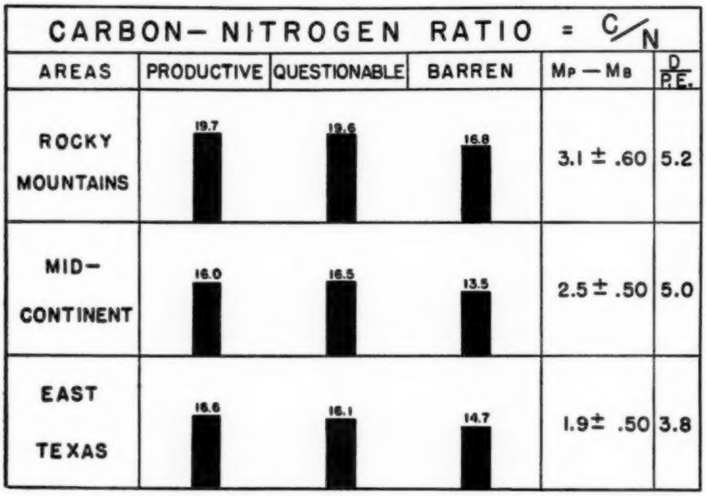

FIG. 6.—Relation of carbon-nitrogen ratio, C/N, to productivity. Numbers above blocks represent average carbon-nitrogen ratios. See Figure 1 for explanation.

greater than in the "productive" beds, but, as mentioned in connection with the description of the method of determining the degree of volatility, this difference is probably anomalous.

Carbon-nitrogen ratio.—The ratio of carbon to nitrogen is distinctly higher for the "productive" than for the "barren" beds in the Mid-Continent, East Texas basin, and the Rocky Mountains, which are the only areas in which the ratio has been studied sufficiently to warrant the presentation of data (Fig. 6). In these three regions the quotient of the difference and its probable error ranges from 3.8 to 5.2. The ratio varies in size in the different areas. In the Rocky Moun-

tain area the average is about 18, in the Mid-Continent and the East Texas basin it is about 16, and in California, about 14. Consequently if this ratio is used as a means of identifying source beds, an estimate of the general average for the individual areas under consideration would first need to be obtained. Like the other properties studied, the individual ratios vary considerably from the average. Some "productive" beds have low ratios and some "barren" beds have high ratios, but the "productive" beds more commonly have high ratios than the "barren." The carbon-nitrogen ratio, therefore, offers fair encouragement in the study of source beds.

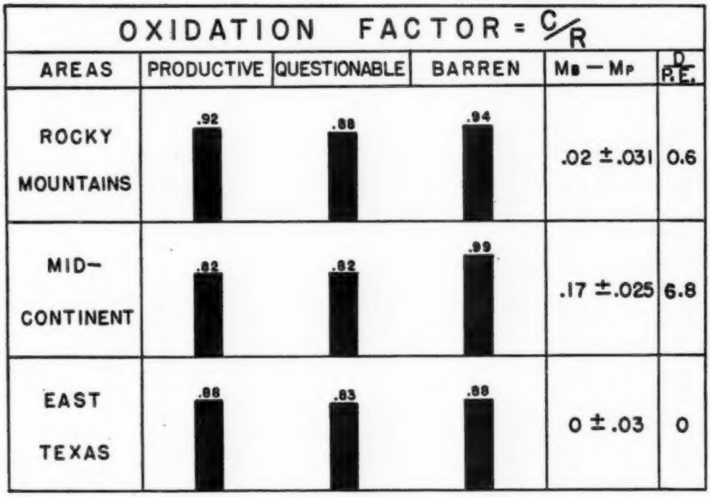

Fig. 7.—Relation of oxidation factor to productivity. The oxidation factor, C/R, is the ratio of the carbon content, C, to the reducing power, R. Numbers above blocks indicate average oxidation factors. See Figure 1 for explanation.

Oxidation factor.—The oxidation factor has been studied in three areas, the Rocky Mountain, the Mid-Continent, and the East Texas basin (Fig. 7). In the first and last of these areas the average is essentially the same for the "productive" beds as for the "barren" beds, but in the Mid-Continent region it is distinctly lower for the "productive" beds than for the "barren." The general average of the factor is approximately the same, 0.9, for the three regions. The oxidation factor, owing to its relative uniformity from region to region, would be a desirable factor to use, but unfortunately it has not yet proved sufficiently distinctive to be particularly encouraging.

Nitrogen-reduction ratio.—In each of the five petroliferous provinces that have been studied, the nitrogen-reduction ratio is decidedly lower in the "productive" beds than in the "barren" (Fig. 8). The quotient of the difference and probable error ranges from 4.8 for the Gulf Coast sediments to 11.3 for the Mid-Continent. The ratio differs in size in the different areas, owing in part to the varying content of nitrogen in the organic matter. The ratio is low in the Rocky

NITROGEN—REDUCTION RATIO = N/R

AREAS	PRODUCTIVE	QUESTIONABLE	BARREN	$M_B - M_P$	$\frac{D}{P.E.}$
CALIFORNIA	6.0	6.0	6.8	0.8 ± .13	6.1
ROCKY MOUNTAINS	4.6	4.7	6.1	1.5 ± .15	10.0
MID-CONTINENT	5.4	5.2	7.9	2.5 ± .22	11.3
EAST TEXAS	4.8	5.0	6.1	1.3 ± .17	7.6
GULF COAST	4.7	4.3	6.7	2.0 ± .42	4.8

FIG. 8.—Relation of nitrogen-reduction ratio to productivity. The nitrogen-reduction ratio, N/R, is the ratio of the nitrogen content, N, to the reducing power, R. Numbers above blocks indicate average nitrogen-reduction ratios. See Figure 1 for explanation.

Mountain region, where the sediments are relatively poor in nitrogen, and it is high in California, where they are comparatively rich in nitrogen. Consequently in using the nitrogen-reduction ratio one should take care first to ascertain the relative nitrogen content of the sediments.

The nitrogen-reduction ratio ranges mainly between 3.0 and 9.0. The general average is about 5.4. Relatively few "productive" beds have a ratio greater than 7.0 and correspondingly few "barren" beds

have a ratio less than 4.5. The consistency with which this ratio has been found to hold in each of the five general regions studied and the general similarity of the ratio in the different areas examined suggest strongly that it may prove to be a useful index of source beds.

TABLE I

RELATIVE RANK OF PROPERTIES AS POSSIBLE MEANS OF RECOGNIZING SOURCE BEDS

Property	*Relative Rank*
1. Nitrogen-reduction ratio	Very good
2. Degree of volatility	Fairly good
3. Volatility	Fair
4. Carbon-nitrogen ratio	Fair
5. Reducing power	Poor
6. Oxidation factor	Poor
7. Color	Poor
8. Organic content	Poor

Relative ranking of properties.—The study of these eight properties indicates that they differ in their promise as a means of recognizing source beds. An attempt to rank them in order of the encouragement they offer is indicated in Table I. The carbon-nitrogen ratio, the volatility, and degree of volatility offer fair promise. The organic content, color, oxidation factor, and reducing power seem to offer little promise. The nitrogen-reduction ratio is the only one of the eight properties that is particularly encouraging.

SIGNIFICANCE OF DATA

Although sufficient work has now been done to suggest that sediments near oil zones in general have low nitrogen-reduction ratios, some sediments located near oil zones have high ratios and some sediments far from oil zones have low ratios. The nitrogen-reduction ratio therefore can not be used as an absolute index of source beds. What then is the proper appraisal of its value? To what extent are the apparent exceptions real exceptions?

Some of the anomalies may be due to irregular distribution of source material among the units studied. The data were compiled as averages for sequences of sediments that range in thickness from 50 to 500 feet. In some of the sequences, more of the beds may be poor in source material than are rich in such material, and because of this some of the exceptions to the relationship may be explained as due to variations in the distribution of source material and not to the inadequacy of the relationship.

The nitrogen-reduction ratio at best can be only one of several

factors that influence the generation of oil. Although it may commonly vary in the same way as most of the other factors and thus in general be an index of source beds, other factors in some strata may be more dominant. The nitrogen-reduction ratio, therefore, can advantageously be examined in more detail to see how it applies to a number of individual sequences of sediments in an oil area. The Mid-Continent has been selected for the first study of this type.

SEQUENCES OF SEDIMENTS STUDIED

Sediments from five general areas located on a southerly trending line from central Kansas to south-central Oklahoma were studied. These five areas are: Ritz-Canton area in McPherson County in

TABLE II

RELATION OF NITROGEN-REDUCTION RATIO TO PRODUCTION OF OIL IN OKLAHOMA AND KANSAS

Lithologic unit	*Ritz-Canton Area, McPherson Co., Kans.*		*El Dorado Field, Kans.*		*Burbank Area, Oklahoma*		*Okla. City Field, Oklahoma*		*Seminole Area, Oklahoma*	
	N/R	*Oil*	*N/R*	*Oil*	*N/R*	*Oil*	*N/R*	*Oil*	*N/R*	*Oil*
Lower part of Permian	*M*	*O*−					*H*	−		
Wabaunsee	*L*	*O*	*L*	+	*L*	−	*H*	−		
Shawnee	*L*	*O*	*M*	*O*	*H*	−	*H*	−		
Douglas	*L*	*O*	*H*	*O*	*H*	−	*H*	−		
Lansing	*L*	+	*M*	*O*+	*H*	−*O*	*H*	−*O*		
Kansas City	*L*	+	*M*	*O*+	*M*	*O*	*H*	−*O*		
Marmaton	*L*	+*O*	*M*	*O*	*M*	*O*	*H*	−*O*		
Cherokee	*H*	*O*+	*H*	*O*+	*M*	+	*H*	*O*+		
Mississippi lime*	*M*	*O*+			*M*	*O*+			*M*	*O*+
Kinderhook	*M*	*O*								
Chattanooga	*L*	+			*L*	+*O*			*M*	+
Hunton	*L*	+							*M*	+
Sylvan	*L*	+*O*							*M*	*O*+
Viola	*L*	+	*L*	+					*L*	+
Simpson	*L*	+	*L*	+	*L*	+*O*	*L*	+	*L*	+
Arbuckle	*L*	+			*M*	*O*	*H*	+	*L*	+

N/R, average nitrogen-reduction ratio; *Oil*, production of oil in or adjacent to the lithologic unit considered; *L*, lithologic units in which the average nitrogen-reduction ratio is 5.0 or less; *M*, units in which the average ratio is 5.1 to 6.5; and *H*, units in which the average ratio is 6.6 or higher; +, good commercial production within or immediately adjacent to the lithologic unit considered; *O*, minor production or shows of oil or production or shows of gas; −, units in which no production is known; dual symbols represent ratings more or less intermediate between the two ratings indicated by the two symbols used.

* In the Seminole area this part of section consists of Caney shale and Mayes limestone.

central Kansas; El Dorado field in Butler County in south-central Kansas; Burbank field in Osage County in north-central Oklahoma; Oklahoma City field in Oklahoma County in central Oklahoma; and the Seminole area in Seminole County in south-central Oklahoma.

The nitrogen-reduction ratios of sediments from 1 to 20 wells in each of these general areas were averaged for each of several sequences of sediments in each area. The sequences in general conform to formations or to groups of formations. Although it is desirable to compare sequences of strata of similar stratigraphic age in the different areas, such a comparison is not yet possible, because of variation in lithology from area to area. An attempt, however, has been made to indicate the correlative stratigraphic equivalents of the strata in the different areas.

The average nitrogen-reduction ratio for each of these sequences of sediments for which data are available are presented in Table II. Sequences in which the average carbon-nitrogen ratio is 5.0 or less are classified as low, *L*, and hence as favorable; those in which it ranges from 5.1 to 6.5, as medium, *M*, or neutral; and those in which it is greater than 6.6, as high, *H*, or unfavorable.

Certain features are apparent from this table. The Ritz-Canton area in Kansas is characterized by generally low carbon-nitrogen ratios and hence would appear to be relatively rich in source material. The pre-Mississippian formations in nearly all areas have low ratios and hence would receive a favorable rating. The nitrogen-reduction ratios of the Pennsylvanian formations, on the whole, increase from central Kansas toward Oklahoma City; consequently the apparent ability of the Pennsylvanian rocks to generate oil would decrease in general from Kansas toward central Oklahoma.

OCCURRENCE OF OIL

The distribution of oil and gas among these sequences of strata affords a possible means of testing the validity of the assumption that the nitrogen-reduction ratio is an index of the ability of sediments to generate oil, because, as was discussed above, oil in general seems more likely to accumulate near than far from its place of origin. The sequences of sediments accordingly have been rated on a three-fold basis with respect to the quantity of oil or gas they contain in the different areas studied (Table II). Positive ratings, +, have been given to formations that contain considerable oil and from which good production has been obtained. Formations such as the Chattanooga shale, adjacent to producing horizons, which from their geologic relations seem good source beds of oil, have also been given a favorable rating.

Sediments in which minor production of oil, or shows of oil, or production or shows of gas are found, have been given a neutral rating, *O*. Some formations that do not yield oil in the immediate vicinity of the areas in which the samples were obtained, but which do yield oil in near-by areas, such as the Layton sand in strata of Kansas City age in the Burbank area, are also given a neutral rating, because of the presumption that they might have yielded oil had the structural or other conditions been more favorable. Formations that are characterized by their barrenness of oil or gas are given a negative rating, −.

This basis of classification is somewhat arbitrary. The ratings of the different lithologic units have been submitted to several geologists who are well acquainted with the oil zones in Oklahoma and Kansas. These geologists agreed in general with the writer's appraisal of the distribution of oil and gas, but preferred to give some of the sediments different ratings. Moreover, the different critics did not agree among themselves. Dual ratings were, however, given to the particular units about which difference of opinion existed.

A detailed account of the reasons for giving the particular ratings to the individual formations is not included in this paper, because of the large amount of space required to discuss the subject. A full statement is planned for inclusion in a comprehensive report, now in preparation, on the study of source beds.

CORRELATION OF NITROGEN-REDUCTION RATIOS WITH THE APPARENT ABILITY OF THE SEDIMENTS TO GENERATE OIL

In order to illustrate better the correlation between the nitrogen-reduction ratio and the oil content of the sediments, the data in Table II have been summarized in Tables III and IV. In Table II, both the nitrogen-reduction ratio and the oil content have been segregated into 3 classes each. Accordingly there are 9 possible combinations of the ratio and the oil content. The lithologic units reported in Table II have been classified according to these 9 combinations in Table III. Two sets of data are given in this table, one for a favorable interpretation of the oil content as indicated in Table II and one for an unfavorable interpretation. For example, in Table II the lower part of the Permian in the McPherson County area in Kansas is given a dual rating, neutral (*O*) and negative (−). The nitrogen-reduction ratio is in the medium (*M*) class. The most favorable interpretation of the oil content would be neutral (*O*), as that would correspond with the medium (*M*) class of the nitrogen-reduction ratio. The least favorable interpretation would be negative (−) as that would not correspond

so well with a medium (M) ratio as would a neutral (O) rating for the oil content.

The 9 possible combinations of nitrogen-reduction ratio and oil content can be classed into 3 groups (Table IV): (1) good, which has 3 combinations in which the ratio and oil content are similar,—low ratio and positive oil content ($L+$), medium ratio and neutral oil content (MO), high ratio and negative oil content ($H-$); (2) fair, which has 4 combinations,—low ratio and neutral oil content (LO), medium ratio and high or low oil content ($M+$, $M-$), and high ratio and neutral oil content (HO); and (3) poor, which has 2 combinations that are as far apart as possible,—low ratio and negative oil content ($L-$) and high ratio and positive oil content ($H+$). The data in Table IV, as in Table III, are classified according to the two interpretations of the oil content.

TABLE III

SUMMARY OF THE RELATIONSHIP OF NITROGEN-REDUCTION RATIO TO PRODUCTION OF OIL

Relationship	*Interpretation*		*Relationship*	*Interpretation*		*Relationship*	*Interpretation*	
N/R-oil	*Favorable*	*Unfavorable*	*N/R-oil*	*Favorable*	*Unfavorable*	*N/R-oil*	*Favorable*	*Unfavorable*
	Number of units			*Number of units*			*Number of units*	
$L+$	18	14	$M+$	3	9	$H+$	1	4
LO	3	7	MO	13	6	HO	4	5
$L-$	1	1	$M-$	0	1	$H-$	10	6
Total	22	22		16	16		15	15

Owing to the uncertainty of the proper ratings for some of the sedimentary units with respect to their ability to generate oil, two interpretations have been included in this table: 1, a favorable interpretation for the rating most favorable to the N/R rating, and 2, an unfavorable interpretation, for the rating least favorable to the N/R rating. The favorable interpretation is based on the first of the two ratings indicated for stratigraphic units for which dual ratings are given in Table II; the unfavorable interpretation is based on the second rating indicated for stratigraphic units for which dual ratings are given in Table II.

According to the most favorable interpretation of the oil content, 41 units or 77 per cent have a good correlation, 10 units or 19 per cent have a fair correlation, and only 2 units or 4 per cent have a poor correlation; and for the unfavorable interpretation, 26 units or 49 per cent have a good correlation, 22 units or 42 per cent have a fair correlation, and 5 units or 9 per cent have a poor correlation (see Table IV). The proper figures presumably are somewhere between these extremes. Even according to the most adverse interpretation, the

percentage of good correlation, which is 49 per cent, is very much greater than that of the poor, which is 9 per cent.

This is a very definite preponderance that can hardly be ascribed to chance. If the mean between the favorable and adverse interpretations be taken, 63 per cent of the sequences have a good correlation compared with 7 per cent for poor correlation. These two classes of correlation account for 70 per cent of the lithologic units considered. The remaining 30 per cent indicate neither a particularly good nor a particularly poor correlation, and could be presumed to be half favorable and half unfavorable. On this basis, 63 plus 15, or 78 per cent, would be favorable, and 7 plus 15, or 22 per cent, would be unfavorable. Thus, the odds in favor of the nitrogen-reduction ratio having a good correlation with the presence of oil in the adjacent sediments would be 78 to 22, or 7 to 2, which in round numbers is about 3 to 1. If all the 30 per cent are regarded as adverse, which is improbable, the odds would be 63 to 37, or 5 to 3, which in round numbers is about 2 to 1.

TABLE IV

CORRELATION OF N/R AND OIL CONTENT

Correlation of N/R and oil ratings	*Interpretation*			
	Favorable	*Unfavorable*	*Favorable*	*Unfavorable*
	Number		*Percentage*	
Good ($L+$, MO, $H-$)	41	26	77	49
Fair (LO, $M+$, $M-$, HO)	10	22	19	42
Poor ($L-$, $H+$)	2	5	4	9
Total	53	53	100	100

In the first column the pairs of symbols refer to the relationship of N/R to *oil*, as indicated in Table III. The favorable and unfavorable interpretations are on the same basis as in Table III.

These odds are not to be considered as indicating that they represent the exact degree of reliability of the nitrogen-reduction ratio as an index of source beds. The oil content is not an entirely adequate means of indicating the apparent ability of the sediments to generate oil, and also, as already discussed, not all the exceptions can be considered as necessarily indicating adverse relations. The odds, however, are sufficiently one-sided to indicate that the nitrogen-reduction ratio very probably is related to the oil content of adjacent sediments. If the original assumption of general shortness of migration is correct, the ratio is related to the generation of oil and to source beds.

Another line of evidence also indicates that a low nitrogen-

reduction ratio may be an index of source beds. Petroleum consists of compounds relatively low in nitrogen compared with the organic constituents of sediments. Accordingly it might be expected to be derived from organic compounds similarly low in nitrogen and therefore from sediments that were comparatively poor in nitrogen. Sediments that have low nitrogen-reduction ratios in general contain relatively little nitrogen. Consequently the sediments near oil zones that have low ratios may in large part really be source beds. Petroleum likewise is composed of highly reduced compounds; hence the sediments from which it is derived may also be relatively rich in reduced compounds. As indicated above, low nitrogen-reduction ratios indicate a high degree of reduction. This reduced state of the sediments near oil zones, therefore, is in accordance with the hypothesis that such sediments are rich in source material.

The argument might be raised, however, that since the nitrogen-reduction ratio is determined in sediments that already may have yielded oil, high ratios instead of low ratios might be expected to be indications of source beds. The sediments that had high nitrogen-reduction ratios might be considered as spent source beds and sediments that had low nitrogen-reduction ratios might be regarded as sediments that had not yet generated any oil.

If the proportion of organic matter that is transformed into oil is large, this possibility merits serious consideration, because the removal of a large part of the organic matter rich in reduced substances might cause the residual material to be decidedly poorer in such substances than if little or none had been removed. On the other hand, if the proportion of organic matter that is transformed into oil is small, even though the part that is removed may be rich in reduced substances, the loss of a small part of the organic matter would not seriously change the relative proportions of the constituents of the residue.

Consequently special attention has been given to the proportion of organic matter that is transformed into oil. The conclusion has been reached that ordinarily it is small, probably less than 10 per cent of the organic matter in the sediments.[10] Hence, the removal of 10 per cent of the original quantity of material, even though relatively rich in reduced substances, would not change the state of reduction of the residual organic material to any great extent. Accordingly, it would seem as if the present organic constituents of source beds would be more likely to be rich than poor in reduced substances.

[10] P. D. Trask, "The Proportion of Organic Matter Transformed into Oil in the Santa Fe Springs Field, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), pp. 245–57.

Source beds, therefore, might be expected to have a low nitrogen-reduction ratio. Since oil zones are commonly located near sediments that have a low nitrogen-reduction ratio, it might be inferred that the oil ordinarily had not migrated far. The original assumption of shortness of migration accordingly would be reasonable.

However, whether oil ordinarily migrates a short distance or a long distance, the fact remains that 5,000 determinations of the nitrogen-reduction ratio from many areas and from a large number of stratigraphic horizons in each of 5 petroliferous provinces, California, Rocky Mountains, Mid-Continent, East Texas basin, and the Gulf Coast, exhibit a definite and distinct relationship to the present occurrence of petroleum. The accordance is too widespread to be accidental. The relationship is not absolute, but it shows a definite preponderance that in terms of chance is somewhere in the neighborhood of 2 to 1 or 3 to 1; that is, the effectiveness of the nitrogen-reduction ratio as an index of source beds seems to be of the order of magnitude of 65 to 75 per cent for the strata studied. Sediments in which the ratio is low are more likely to be near oil zones than far from oil zones, and sediments in which the ratio is high are more likely to be far from oil zones than near to them. A genetic relationship to the generation of oil seems apparent, but even if there is no genetic connection, the inference seems warranted that if the sediments in an area have low nitrogen-reduction ratios, the probabilities are good that oil will be found in the area, provided structure and reservoir conditions are favorable. The ratio, therefore, merits further study in order to ascertain more fully the extent to which it may be applied to the problem of source beds.

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PENNSYLVANIAN SEDIMENTATION IN ARKANSAS COAL FIELD[1]

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ABSTRACT

About 13,000 feet of Pennsylvanian strata (of upper Pottsville and lower Allegheny age) are present in the southern part of the Arkansas coal field. The strata thin northward at such a rapid rate that they are only about half as thick at the north side of the coal field as equivalent strata at the south side. The sediments in the Pottsville portion of the section consist dominantly of shale, sandy shale, and sandstone, and the overlying strata of Allegheny age consist of these lithologic types together with a number of coal beds. The major source of the sediments appears to have been farther south, in and south of the Ouachita Mountains, but some sediments in the lower part of the section probably came from the east.

Deposition of the Pennsylvanian sediments took place in a basin: (1) that was progressively warped downward and whose north margin migrated northward across the area but lay across the central part of the coal field during most of early Atoka time; (2) that underwent minor deformation by lateral pressure from the south during the deposition of the sediments; (3) that stood close to sea-level throughout the greater part of the time of deposition of the sediments; (4) that received no invasion of marine waters of sufficient depth or duration to leave a perceptible record in the stratigraphic column; and (5) that received the bulk of the sediments under fluviatile conditions. In consequence of these and other conditions the Arkansas coal field is characterized by (1) northward thinning of the strata, part of which is due to progressive northward overlap at the base of the Atoka formation and part to northward thinning of individual beds; (2) a sharp change in the structural pattern along an east-west line which probably marks the zone of greatest change in thickness of the coal-basin strata; (3) limited lateral extent of lithologic units; and (4) no apparent symmetry of recurrence of lithologic types in the stratigraphic column.

INTRODUCTION

The coal field in Arkansas and its westward continuation into Oklahoma for a distance of about 150 miles lie on the north flank of the large Pennsylvanian geosyncline of the Ouachita Mountains of Arkansas and Oklahoma (Fig. 1). In early Pennsylvanian time it was an area of clastic deposition in which the thickness of the sediments diminished rapidly northward. The sediments in the Arkansas part of the field are almost entirely nonmarine, but in the western part of the Oklahoma coal field many marine beds are present. On the basis of the distribution of marine sediments in Oklahoma it appears probable that the eastern margin of a Pennsylvanian sea extended north-northeastward across the western part of the Oklahoma coal area and that the margin of the sea moved eastward or westward

[1] Published by permission of the director, United States Geological Survey. Manuscript received, September 13, 1937.

[2] United States Geological Survey.

many miles at various times during the deposition of the Pennsylvanian strata.

In this paper it is proposed to discuss the probable conditions of deposition and source of the sediments as suggested by the lithology of the strata, by the lateral extent of the individual beds, by the stratigraphic relationship between lithologic types, and by the nature of the variations in thickness of the strata.

FIG. 1.—Index map showing location of Arkansas and Oklahoma coal fields in relation to surrounding physiographic divisions.

NATURE OF NORTHWARD THINNING OF STRATA

The Atoka formation[3] is the oldest of the formations of geosynclinal facies in the Arkansas coal field and is present beneath the entire area. The younger formations,[4] Hartshorne sandstone, McAlester shale, Savanna sandstone, and Boggy shale, have been removed by erosion over much of the area. Consequently the Atoka formation offers more information on regional thinning than the overlying formations. In addition, the Atoka formation contains several gas-bearing sandstones; and the logs of numerous wells drilled through them furnish additional data on the stratigraphy of the formation.

[3] T. A. Hendricks, C. H. Dane, and M. M. Knechtel, "Stratigraphy of Arkansas-Oklahoma Coal Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 10 (October, 1936), pp. 1343–56.

[4] T. A. Hendricks, C. H. Dane, and M. M. Knechtel, *op. cit.*

The Atoka formation consists of alternating beds of sandstone and shale with a few discontinuous streaks of coal present locally in the shale. The sandstones vary greatly in thickness and lithology, both from bed to bed and from place to place in a single bed. In general the sandy zones continue for considerable distances, although a thick, massive, coarse-grained sandstone within such a zone may grade laterally into a sandy shale that is considerably thinner. The sandstones vary from coarse-grained, almost white and pure, to fine-grained, brownish, and very shaly. Considerable amounts of mica are present in the sandstones at all places. At some places in the area sandstone beds in the Atoka formation thicken from 10 or 15 feet to as much as 150 feet in distances of $\frac{1}{4}$–$\frac{1}{2}$ mile, from which they thin down to 10 or 15 feet in the succeeding $\frac{1}{4}$–$\frac{1}{2}$ mile. At those places the base of the sandstone cuts downward across the bedding of the underlying shale in the direction of the thickening of the sandstone. Such sandstone beds were deposited in stream channels that cut downward into the underlying shale.

Brownish, sandy, micaceous shale either overlies or underlies the sandstone beds at most, if not all places; and the vertical transitions from sandy shale to shale in one direction and from sandy shale to sandstone in the other direction are gradational. The remainder of the formation consists of black, slightly gritty, splintery shale that contains some coarse mica and very abundant macerated plant material. Where the black shale is either overlain or underlain directly by sandstone the contact between the two lithologic types is sharp. Marine fossils and well preserved plant fossils have been found at only a few localities, and none of the fossiliferous zones can be traced laterally beyond a single exposure.

The lithologic character of the strata of the Atoka formation described in the preceding paragraphs indicates that for the most part the sediments were deposited on a wide, comparatively level surface that stood close to sea-level. If the surface lay close to, but below, sea-level, the water was so shallow that it was subjected to almost continuous agitation and was too turbid to permit the existence of an extensive fauna. If the surface lay above sea-level it must have been comparatively well drained, as otherwise accumulation of plant materials in stagnant marshes would almost certainly have resulted in the formation of lenticular coal beds. The very few lenticular streaks of coaly shale present in the formation indicate that the drainage was not perfect and that some slight accumulation of plant debris did occur locally. It is probable that each of these conditions obtained at various times throughout the period of deposition, and it is also

probable that the two conditions existed simultaneously in different parts of the area. The formation is thick and available faunal and floral evidence[5] shows that it represents only the upper part of the Pottsville. The deposition of such a thick formation in so short a time indicates that the rate of deposition was rapid. Such rapid

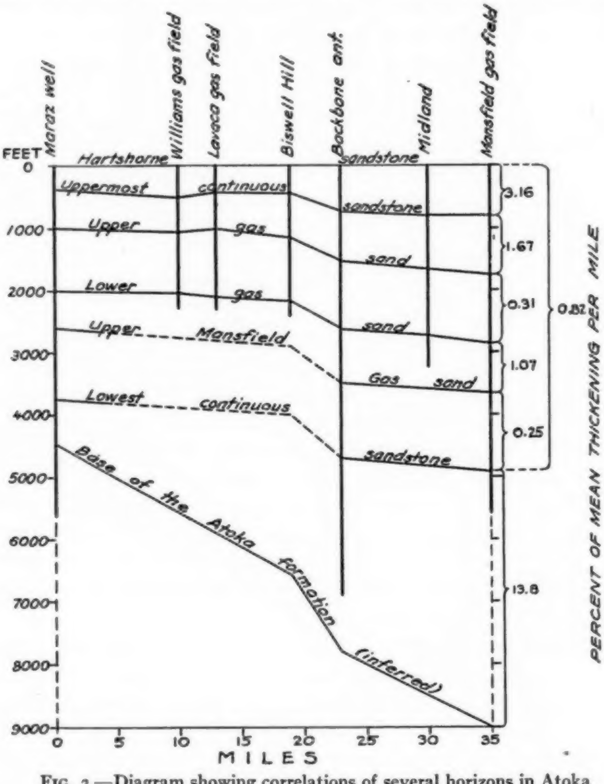

FIG. 2.—Diagram showing correlations of several horizons in Atoka formation from north to south across Arkansas coal field.

deposition of clastic materials would provide an inhospitable environment for both plants and invertebrates, and thus prevent the occurrence of abundant fossiliferous beds in the section.

[5] T. A. Hendricks and C. B. Read, "Correlation of Pennsylvanian Strata in the Arkansas and Oklahoma Coal Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 8 (August, 1934), pp. 1055–56.

David White, "Age of Jackfork and Stanley Formations of Ouachita Geosyncline, Arkansas and Oklahoma, as Indicated by Plants," *Bull. Amer. Assoc. Petrol. Geol., ibid.*, pp. 1016–17.

A complete section of the Atoka formation is obtainable at only one place in the area. That section is supplied by the drill cuttings from the R. A. Maraz Stewart well, No. 1, at the northern boundary of the area northeast of Mulberry. The well starts in the basal part of the Hartshorne sandstone, penetrates all of the Atoka formation, and ends in the Fayetteville shale of Mississippian age (Fig. 2). It is difficult to identify the base of the Atoka formation exactly from drill cuttings, but in that well it can be no lower than the base of a sandstone at 4,465 feet, and probably lies at that point. If the base of the formation is at that level the total thickness of the Atoka formation is 4,450 feet.

The Atoka formation is about 9,000 feet thick in two areas about 20 miles east and 25 miles west of Mansfield gas field in the southern part of the area. As lines of equal thickness of the formation trend east and west, it is probable that the thickness of the Atoka formation is approximately 9,000 feet in the Mansfield gas field at the south side of the area and about 35 miles south of the Maraz well. Therefore, the Atoka formation thickens southward about 4,550 feet in 35 miles, or at an average rate of 130 feet per mile. In the following discussion the writer has attempted to analyze the nature of that thickening.

In Figure 2, correlations of the upper part of the Atoka formation in a series of stratigraphic sections along a north-south line across the area are shown. All sections were obtained from well logs except the one on the Backbone anticline, which was computed from outcrops. From the figure it is apparent that there is a gradual progressive southward thickening of the strata between the highest and lowest continuous sandstone beds in the formation. The uppermost 3,750 feet of the Atoka strata in the Maraz well thicken to 4,925 feet in the Mansfield gas field, or at an average rate of 0.82 per cent per mile. The writer was unable to correlate all of the lower 700 feet of strata in the Maraz well with sections farther south because these strata were not penetrated in other wells. However, the top of a sandstone bed which lies at the top of that 700-foot zone in the Maraz well correlates with the top of a sandstone and sandy shale horizon 4,075 feet above the base of the Atoka formation in the Mansfield gas field. Therefore, the lower part of the formation thickens 3,375 feet from north to south across the area, or at an average rate of 13.8 per cent per mile. This rate of thickening is about 17 times as great as the 0.82 per cent per mile rate in the upper part of the formation and must be due to markedly different processes.

This great thickening in the lower part of the formation probably is due to deposition in a basin undergoing progressive downwarping

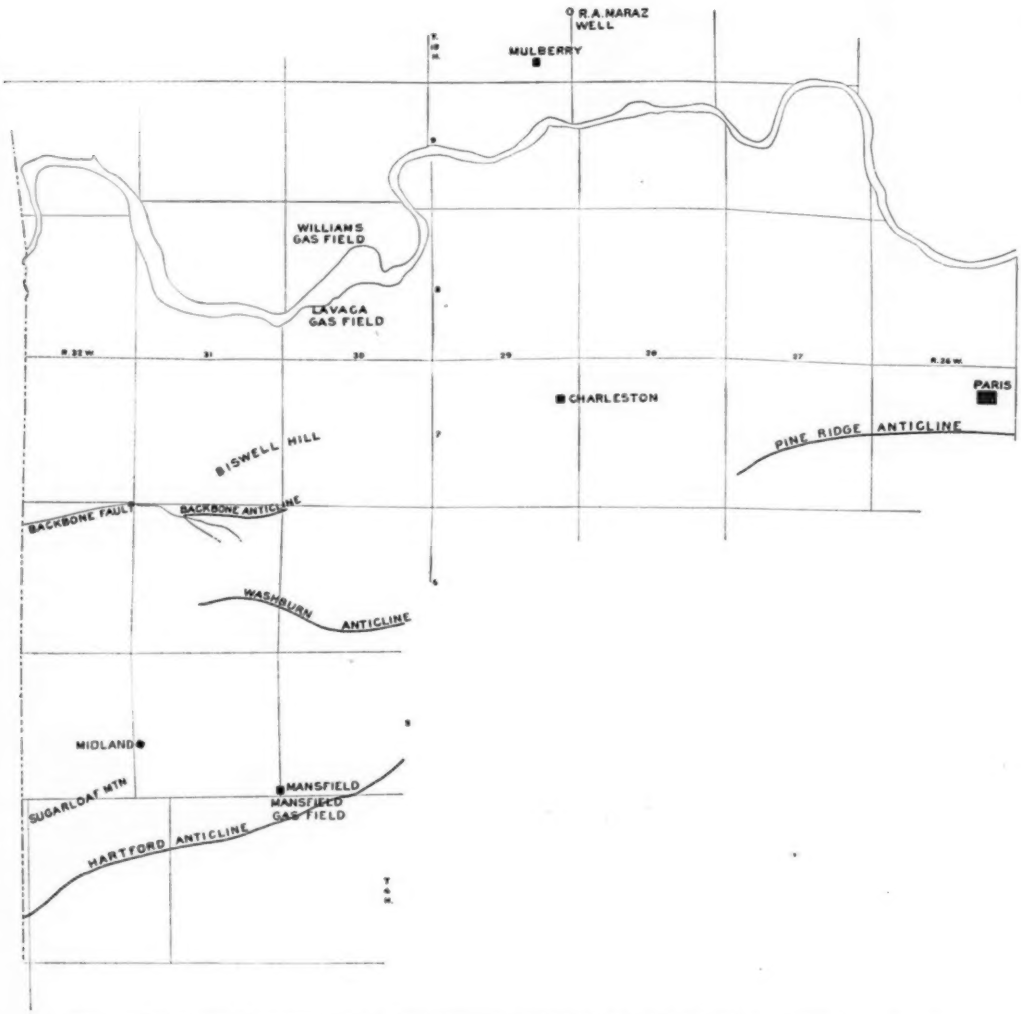

FIG. 3.—Index map of western part of the Arkansas coal field showing location of points mentioned in text.

and whose northern margin either lay within the area or migrated northward across the area. In that case the lower 700 feet of strata in the Maraz well may thicken southward at a rate comparable with that of the overlying units (0.82 per cent per mile) and their thickened equivalents may represent only about 900 feet of the strata immediately below the top of the lowest continuous Atoka sandstone bed in the Mansfield gas field. If that is true, the lower 3,175 feet of Atoka strata in the Mansfield area are absent in the Maraz well.

In the Boston Mountains north of the coal basin the Atoka formation is underlain by strata of the thin Morrow group. The thickness of the Morrow group does not vary greatly either along the south side of the Boston Mountains or northward across the mountains, and no channelling or other topographic irregularities suggestive of high relief have been observed at the top of the group. It seems apparent, therefore, that immediately prior to Atoka deposition the land surface along and north of the margin of the coal basin lay so close to sea-level that there was here neither deposition of strata equivalent to the lowest Atoka strata present farther south nor marked stream erosion of the underlying strata of the Morrow group. In later Atoka time, however, the north margin of the geosyncline moved northward and thus permitted the deposition of the several thousand feet of younger Atoka strata in the Boston Mountains.

Progressive northward overlap at the base of the Atoka formation has been observed in the Muskogee-Porum district by Wilson and Newell,[6] but overlap within the Atoka formation has not been observed in eastern Oklahoma or Arkansas. Furthermore no change in facies from north to south has been observed in either of those areas.

The features just mentioned suggest that minor downwarping occurred on the south side of a series of northward-migrating axes throughout early Atoka time. The strata deposited south of each of the axes would be overlapped by the strata of the next younger basin. The only plane of overlap would therefore lie at the base of the Atoka formation. Continued migration of such axes of downwarping northward beyond the Arkansas coal field throughout later Atoka time would offer an adequate explanation of the gradual southward thickening of the upper part of the formation without any appreciable facies change.

The present structural pattern of the Arkansas coal field suggests that the greatest part of the increase in thickness of the lower part of the Atoka formation occurred south of the Backbone anticline.

[6] C. W. Wilson, Jr., and N. D. Newell, "Geology of the Muskogee-Porum District. Oklahoma." (In preparation by the Oklahoma Geological Survey.)

This change in the structural pattern of the Arkansas coal field takes place along a narrow belt that extends almost due eastward from the Backbone anticline at the Arkansas-Oklahoma state line to the north side of the Pine Ridge anticline south of Paris. North of that zone the anticlines are gentle open folds, but south of it the anticlines are tightly folded as a result of compressive forces exerted from the south.[7] In materials of comparatively uniform character a gradual transition from closely compressed anticlines at the south to slightly compressed anticlines at the north would be expected, and the abruptness of the change in structure just mentioned, suggests a pronounced change in the character of the strata. A substantial change in the character of the materials would have been effected by the existence of the northern margin of the geosyncline near the position of Backbone anticline throughout most of early Atoka time. Depression of the basin south of that margin would have resulted in the deposition of a considerable thickness of Atoka strata not present farther north. North of the Backbone anticline the Atoka strata, as shown by deep well data, are underlain at a comparatively shallow depth by limestone and sandstone strata that are far more competent than the Atoka itself. Therefore, an abrupt southward increase in thickness of the Atoka formation would materially increase the thickness of incompetent surficial strata in that direction. Such a change seems adequate to explain the abrupt change in structural pattern in the central part of the Arkansas coal field.

The thickening of the part of the Atoka formation above the highest continuous sandstone is variable rather than progressively southward (Fig. 3). The thickening in that zone is northward from the Lavaca gas field to the Williams gas field, and between Biswell Hill and the Backbone anticline is southward at the very high rate of 19.44 per cent per mile. It is probable that those deviations from the normal southward thickening are due to structural movements that occurred after the deposition of the highest of the Atoka sandstones and before the deposition of the Hartshorne sandstone. As a minor unconformity is present at the base of the Hartshorne sandstone, it appears probable that the area between Backbone Ridge and the Williams gas field was warped upward at the end of Atoka time and that erosion then removed some of the uppermost strata from that area. Each of the lower horizons (Fig. 2) was affected by the upwarp.

[7] T. A. Hendricks and Bryan Parks, "Geology and Mineral Resources of the Western Part of the Arkansas Coal Field," *U. S. Geol. Survey Bull. 847-E* (1937), pp. 201–03.

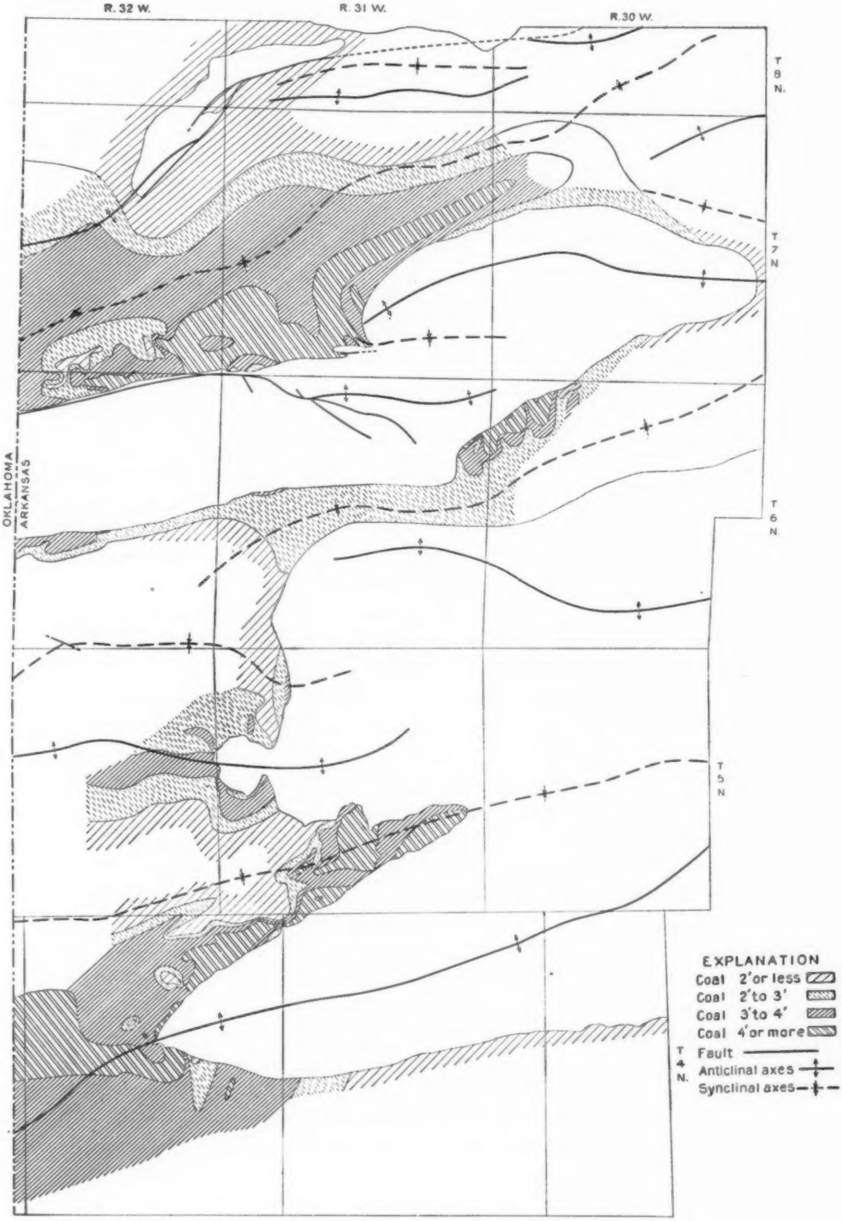

FIG. 4.—Map showing thicknesses, in feet, of Lower Hartshorne coal and positions of structural axes in extreme western part of Arkansas coal field.

STRUCTURAL MOVEMENTS DURING THE PERIOD OF DEPOSITION

An isopach map (Fig. 4) of the Lower Hartshorne coal shows a marked parallelism between the trends of the major belts of thick and thin coal and the trends of the structural axes that exist in the Arkansas coal field to-day. The parallelism suggests that the surface of coal deposition was irregular and that the irregularity was the result of topographic expression of minor structural features. The major factor that would control the variations in thickness of a single coal bed is variation in the position of the surface of deposition in relation to the existing water level. If the surface on which potential coal-forming materials were laid down was well above the existing water level, oxidation would have destroyed most of the potential coal-forming materials, and an area of thin coal would result. If the surface of deposition of potential coal-forming materials was far below the existing water level, plant growth would be materially decreased and the supply of coal-forming materials correspondingly reduced. If the surface on which the coal-forming materials were deposited was irregular prior to the deposition of the plant material, the higher ridges might stand too far above the water level and the deeper troughs too far below the water level for optimum conditions of preservation of the plant material on the ridges and of growth of plant material in the troughs. As a result thin coals would be formed from the materials deposited both on the ridges and in the troughs. The crests of other ridges may have lain close to the water level and would have offered optimum conditions for plant growth and preservation. Likewise the bottoms of some troughs may have lain so close to the water level that optimum conditions for the deposition of coal-forming materials existed there. It is apparent, therefore, that the local topographic character of the floor of deposition can not be established from coal thickness alone, but if the above hypothesis is correct the trends of the topographic features can be established. Minor buckling of the floor immediately prior to coal deposition would have produced a series of anticlinal ridges and synclinal valleys. Therefore, it appears probable that the structural trends of the Arkansas coal field were established as early as the time of deposition of the Lower Hartshorne coal, and that minor compressive forces were exerted from the south during the deposition of the strata in the coal basin.

Another feature present on the flanks of two of the major anticlines, Hartford and Washburn, indicates that at least at some places those two anticlines were growing throughout late Atoka, Hartshorne, and McAlester time, and suggests that the hypothesis that structural

features controlled the distribution of thick and thin coal is not unreasonable. At several places on each of these anticlines sandstone beds in the Atoka, Hartshorne, or McAlester formations contain large plates of shale that lie at angles to the bedding of the enclosing sandstone. The shapes and laminated bedding of the flat plates of shale indicate that they were shale rather than mud at the time of deposition in the sandstone. The fact that large plates of shale disintegrate before they can be transported more than a very short distance indicates that the plates were derived from some near-by source. As the plates of shale are found only in the sandstones on the flanks of anticlines, it seems apparent that during the period of deposition of each of these sandstone beds the central parts of the anticlines were raised sufficiently for previously deposited shales to be eroded.

LATERAL EXTENT AND STRATIGRAPHIC RECURRENCE OF LITHOLOGIC TYPES

The lithologic character of the strata in the Hartshorne sandstone, McAlester shale, Savanna sandstone, and Boggy shale is similar to that of the Atoka formation, but differs in at least two respects. Coal beds, which are represented by only a few discontinuous streaks in the Atoka formation, are numerous in the overlying formations; and only a few very thin shale beds of the younger formations contain the abundant macerated plant material which imparts the characteristic black color to nearly all of the shales of the Atoka formation. Thus, plant material, which is disseminated throughout the greater part of the Atoka strata, tends to be concentrated into a series of coal beds in the overlying formations. This indicates that at many stages in post-Atoka time a comparatively level, poorly drained lowland that received little clastic sediment existed in the geosynclinal area. In those stages the many coal beds were formed.

The introduction of coal beds into the section produces a series of alternating coal, shale, sandy shale, and sandstone beds, and in addition some thin underclays which are locally present beneath the coal beds.

In recent studies of Pennsylvanian strata deposited on comparatively stable platforms, such as those of Illinois, Ohio, and Kansas, considerable attention has been devoted to the stratigraphic sequences of lithologic and faunal units and of the relations of the various units to each other. In each of those areas several distinct lithologic types are present, each of which tends to recur at stratigraphically different horizons with a more or less consistent relationship to individual overlying and underlying lithologic types. That tendency for lithologic

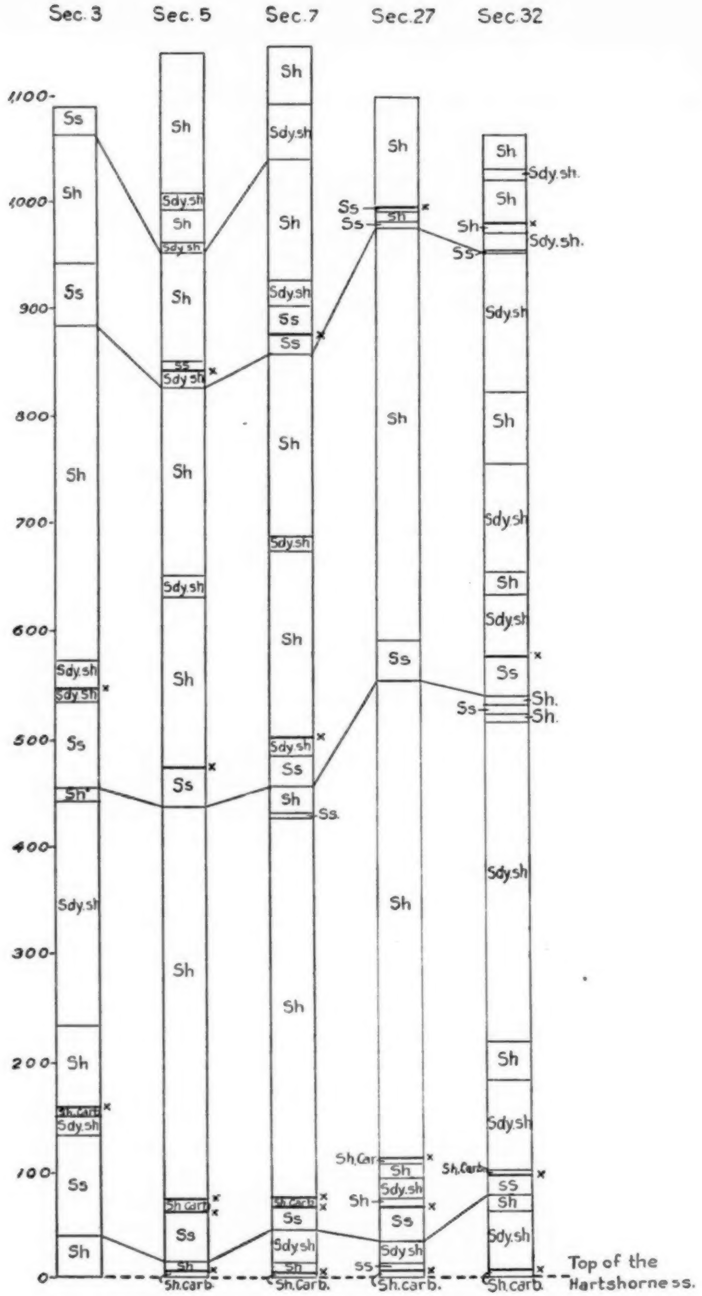

FIG. 5.—Sections of lower part of McAlester shale encountered in five diamond drill holes in T. 4 N., R. 32 W., Arkansas. Coal beds indicated by crosses.

sequences to be repeated throughout the Pennsylvanian strata of such stable platform areas has led a number of workers in this country, notably Udden, Wanless, Weller, Stout, and Moore,[8] to consider each of those sequences a unit which may be used as a basis of a subdivision of the Pennsylvanian strata.

Careful study has been given by the writer to the nature of the Pennsylvanian sediments of geosynclinal facies in the Arkansas Valley region for the purpose of ascertaining the presence or absence of consistent repetition of lithologic sequences throughout the stratigraphic section. In connection with this study about 600 diamond-drill records of strata in the McAlester shale in Sebastian County, Arkansas, have been examined. Five of the deepest diamond drill-holes penetrate about 1,100 feet of strata in the lower part of the formation in Secs. 3, 5, 7, 27, and 32, T. 4 N., R. 32 W., and by virtue of field mapping several stratigraphic horizons can be correlated throughout all five of the drill holes (Fig. 5). Four coal beds are present in the part of the formation penetrated. No semblance of consistency either stratigraphically or laterally in the lithologic sequences appears to have been encountered in the diamond drill holes. The only consistent relationship lies in the alternation of coal beds with undifferentiated clastic sediments, a relationship that obviously would exist in any section consisting of clastic materials and some coal beds. Individual clastic units vary greatly in both lithologic character and thickness in short lateral distances, although the intervals occupied by undifferentiated clastic rocks between coal beds tend to remain fairly constant over distances of 5–10 miles. If the coal beds are absent or not exposed in any two or more given sections the measuring and matching of clastic lithologic types is of little or no value for correlation.

Detailed composite sections of the McAlester shale and Savanna sandstone compiled from diamond drill records and a large number of measured partial sections in the Arkansas coal field were also studied carefully in order to ascertain the presence or absence of stratigraphic repetitions of lithologic sequences in those two formations. The various partial sections previously mentioned were tied together by detailed plane-table mapping on a scale of 2 inches equals 1 mile. The two composite sections are here given.

[8] J. A. Udden, "Geology and Mineral Resources of the Peoria Quadrangle, Illinois," *U. S. Geol. Survey Bull. 506* (1912), pp. 26–50.

H. R. Wanless, "Pennsylvanian Cycles in Western Illinois," *Illinois Geol. Survey Bull. 60* (1931), pp. 179–93.

J. M. Weller, "Cyclic Sedimentation in the Pennsylvanian and Its Significance," *Jour. Geol.*, Vol. 38, No. 2 (1930), pp. 97–135.

Wilber Stout, "Pennsylvanian Cycles in Ohio," *Illinois Geol. Survey Bull. 60* (1931), pp. 195–216.

R. C. Moore, "Pennsylvanian Cycles in the Northern Mid-Continent Region," *ibid.*, pp. 247–57.

COMPOSITE SECTION OF THE MCALESTER SHALE ON THE EAST END OF SUGARLOAF MOUNTAIN, T. 5 N., R. 32 W.

(Brackets and accompanying Roman numeral indicate part of section repeated in Table I)

		Feet	Inches
	1. Shale, gray, sandy, micaceous	250	
	2. Shale, black, carbonaceous, contains ostracods	4	
	3. Coal		3
	4. Shale, black, carbonaceous	1	2
	5. Coal		4
	6. Underclay, hard	2	0
	7. Shale, gray, sandy, micaceous	170	
I	8. Shale, gray, clayey, fissile	5	
	9. Coal, very impure, mostly carbonaceous shale		8
	10. Underclay	1	
	11. Sandstone, hard, dense, dark, stigmarian		8
	12. Sandstone, shaly, olive, soft, micaceous		8
	13. Sandstone, ripple-marked, micaceous, gray, in beds $\frac{1}{8}$-1 inch thick in lower part, increasing progressively to about 3 inches in upper part	80	
	14. Shale, dark gray, micaceous, sandy, grades upward into overlying sandstone	480	
	15. Sandstone, gray, ripple-marked, micaceous, in beds 1–2 inches thick, grades laterally into sandy shale	13	
	16. Shale, dark gray, micaceous, sandy	112	
	17. Shale, very sandy, locally grades into shaly sandstone, buff to gray, micaceous	25	
	18. Coal	1	
	19. Shale, black, carbonaceous	3	
	20. Sandstone, fine-grained, gray, micaceous, ripple-marked, in beds about 1 inch thick, grades downward into sandy shale	30	
	21. Shale, dark, micaceous, somewhat sandy	170	
	22. Shale, gray, micaceous, very sandy	13	
	23. Shale, dark gray, micaceous, slightly sandy	175	
	24. Coal	1	
	25. Shale, black, carbonaceous	3	
	26. Sandstone, gray to buff, micaceous, fine-grained, ripple-marked, thin-bedded, locally grades laterally into sandy shale	47	
	27. Shale, very sandy, micaceous, gray	16	
	28. Sandstone, similar to 26	7	
	29. Shale, similar to 27	6	
	30. Sandstone, similar to 26	9	
	31. Shale, dark gray, micaceous, somewhat sandy	92	
	32. Shale, gray to buff, very sandy, micaceous	124	
	33. Shale, dark gray	27	
	34. Shale, very sandy, micaceous, gray to buff	13	
	35. Shale, dark gray, micaceous	48	
	36. Coal and carbonaceous shale	5	
	37. Shale, black, carbonaceous	3	
	38. Sandstone, buff, fine-grained, micaceous, ripple-marked	17	
	39. Shale, very sandy, gray, micaceous	12	
	40. Coal, impure	2	
	41. Sandstone, coarse-grained, irregularly bedded, gray to white, lenticular with irregular base. Varies from 0 to 54 feet	20	
	42. Shale, sandy, micaceous, gray	30	
	43. Shale, dark, carbonaceous, contains plant fossils and brackish-water invertebrates	7	
	44. Coal (Lower Hartshorne)	4	
	45. Shale, carbonaceous, with coaly streaks. Basal beds of the McAlester shale	3	

COMPOSITE SECTION OF THE SAVANNA SANDSTONE SOUTH OF CHARLESTON, T. 7 N., RS. 28 AND 29 W.

(Brackets and accompanying Roman numerals indicate parts of section repeated in Table I.)

		Feet	*Inches*
	1. Sandstone, thick- and even-bedded, medium-grained, buff, micaceous. Uppermost unit of Savanna sandstone	20	
	2. Shale, gray and sandy	6	
	3. Sandstone, buff, shaly	5	
	4. Shale, gray	5	
	5. Limestone, sandy, fossiliferous, fresh-water fossils	1	
	6. Shale, black, calcareous	2	
	7. Limestone, dark gray, very fossiliferous, hard, silicified	1	
	8. Coal		6
	9. Shale, gray and sandy	6	
	10. Sandstone, brown and shaly, thin-bedded	8	
	10a. Shale, gray and black—some sandy	27	
	10b. Sandstone, marine fossils	2	
	11. Shale, gray in upper part, grading downward into black shale which contains abundant plant fossils	30	
	12. Coal	1	6
IV	13. Shale, gray and black with abundant plant fossils in lower part	110	
	14. Coal		2
	15. Shale, black and gray, with some plant fossils in upper part	70	
	16. Sandstone, brown, fine-grained and shaly	7	
	17. Shale, sandy, gray and black	90	
	18. Sandstone, medium-grained, soft, brown, thin-bedded	5	
	19. Coal		4
	20. Shale, gray	100	
III	21. Coal		4
	22. Sandstone, gray, hard, fine-grained, even-bedded in beds 1–8 inches thick. Used locally for structural stone	20	
	23. Shale, gray and black, with some sandy shale	200	
	24. Sandstone, gray, brown, shaly, even-bedded	8	
	25. Shale, gray and black, and some sandy shale	80	
	26. Sandstone	10	
	27. Shale, gray and black, and some sandy shale	50	
	28. Sandstone	10	
	29. Coal		11
	30. Shale, gray and black, and some sandy shale. Contains two lenticular sandstone beds	160	
	31. Sandstone, brown, even-bedded, shaly brown 1–2 feet, very hard	10	
	32. Shale, sandy, brown, micaceous	15	
	33. Coal		6
II	34. Shale, sandy, banded gray and black, in ¼–½-inch bands resembling varves, contains plant fossils especially in lower part	70	
	35. Coal	1	6
	36. Sandstone, gray to buff, medium-grained to shaly	10	
	37. Shale, gray and some brown sandy shale	200	
	38. Sandstone, brown, fine-grained, thin-bedded, hard, breaks into long narrow rectangular fragments. Basal unit of Savanna sandstone	15	
	Total	1,359	9

In the sections here given there is no apparent sequence that is repeated in the McAlester shale and Savanna sandstone. However, lithologic sequences that are somewhat similar occur at three horizons

in the Savanna sandstone and one horizon in the upper part of the McAlester shale. Those sequences are given in Table I.

TABLE I

SIMILAR LITHOLOGIC SEQUENCES THAT OCCUR AT FOUR HORIZONS IN MCALESTER SHALE AND SAVANNA SANDSTONE

I[a]	II[b]	III[b]	IV[b]
Shale, gray, sandy	shale, sandy	—	shale
	—	—	sandstone, marine
Coal }			
Shale, black, carbonaceous }	coal		
Coal }		coal	coal
Hard underclay	—	—	—
Shale, clayey, fissile, poor plant fossils	shale plants	shale	shale plants
Coal, impure	coal	coal	coal
Underclay }	plant-bearing		
Stigmarian sandstone }	shale (local)	—	shale plants
Sandstone	sandstone	sandstone	sandstone

(a) For position in the McAlester shale and thicknesses, see part of preceding section enclosed by brackets and marked I.
(b) For position in the Savanna sandstone and thicknesses, see parts of preceding section enclosed by brackets and marked with corresponding Roman numerals.

These four sequences represent a total of about 790 feet of a complete section about 3,275 feet thick, and they are all separated by variable sequences of sandstone, sandy shale, and shale, with one coal bed present in all except one of the sequences.

The tendency for lithologic types to recur in similar sequences in the Pennsylvanian strata of the Arkansas coal field therefore appears so slight that such sequences cannot be used for purposes of mapping or correlation.

SOURCE OF SEDIMENTS

Available evidence suggests that most of the Pennsylvanian sediments of the Arkansas coal field came from the south and that a minor amount of sediment came from the east. The presence of abundant marine sediments in the northwestern part of the Oklahoma coal field shows that throughout much of Pennsylvanian time a sea existed in that area and served as a barrier to the transportation of clastic sediments into the Arkansas coal field. In the preceding discussion of the nature of the southward thickening of the strata in the Arkansas coal field it was pointed out that the north margin of the basin of deposition extended across the coal field in early Atoka time but that there is no evidence of stream channeling in the strata north of that margin. The absence of such channels suggests that there were no large southward-flowing streams from the Ozark region that car-

ried sediment into the coal basin. Therefore, major sources of sediment on the north and west seem to be eliminated.

Near Atoka, Oklahoma, in the extreme southern part of the Oklahoma coal basin there are abundant coarse conglomerates in the Atoka, Hartshorne, McAlester, and Savanna formations. A study of the pebbles in the conglomerates indicates that they were derived from a source that lay southeast of the coal basin and within the area now occupied by the Ouachita Mountains.[9]

In the Pine Mountain strip pit near Heavener, Oklahoma, the trunks of numerous *Cordaites* and *Calamites* stand upright in the upper part of the Hartshorne sandstone. Many others have their tops tilted northward at various angles, and still more of them lie flat along the bedding planes with their butts toward the south and tops toward the north.[10] The northward tilting of the trunks indicates that at least locally in Hartshorne time streams entered the coal basin from the south.

Along the southern margin of the Arkansas-Oklahoma coal field and at some places north of that margin, thick, coarse-grained, channeloid parts of the Hartshorne sandstone appear to trend northward and to indicate that the streams that deposited sands of that formation entered the basin of deposition from the south.[11]

The evidence cited indicates that at least locally at various times sediments entered the Arkansas-Oklahoma coal basin from the south, and in the absence of evidence to the contrary it seems probable that the bulk of the sediments came from the south.

According to Miser[12] the source of most of the Pennsylvanian sediments of the Ouachita Mountains and Arkansas Valley was Llanoria, an extensive land area of crystalline rocks that stood south of the Ouachita Mountains in Pennsylvanian time and was later lowered and covered by the sediments of the Gulf Coastal Plain. The Atoka formation contains the youngest rocks in the Ouachita Moun-

[9] T. A. Hendricks, M. M. Knechtel, and Josiah Bridge, "Geology of Black Knob Ridge, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 1 (January, 1937), pp. 14 and 23.

M. M. Knechtel, "Geology and Fuel Resources of the Southern Part of the Oklahoma Coal Field, Part 2, Lehigh District," *U. S. Geol. Survey Bull. 874-B* (1937), pp. 125–26.

[10] T. A. Hendricks, "Geology and Fuel Resources of the Southern Part of the Oklahoma Coal Field, Part 4, Howe-Wilburton District," *U. S. Geol. Survey Bull. 874-D* (in preparation).

[11] T. A. Hendricks, C. H. Dane, and M. M. Knechtel, "Stratigraphy of Arkansas-Oklahoma Coal Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 10 (October, 1936), p. 1348.

[12] H. D. Miser, "Llanoria, the Paleozoic Land Area in Louisiana and Texas," *Amer. Jour. Sci.*, 5th Ser., Vol. 2 (August, 1921), pp. 61–89.

tains. The Hartshorne sandstone and overlying formations are not present in these mountains and may not have been deposited there. It seems possible, therefore, that the previously deposited Pennsylvanian strata of the Ouachita Mountains as well as Llanoria supplied sediments to the coal basin in post-Atoka time.

In the Boston Mountains, north of the Arkansas coal field, there is evidence that some sediments in the Atoka formation were derived from a source that lay at the east. In early reports of the Arkansas Geological Survey the Atoka formation in the Boston Mountains was called the Millstone grit because of the presence of small waterworn quartz pebbles present in sandstones at several horizons. Purdue and Miser,[13] Croneis,[14] and other later writers have also noted the presence of small waterworn quartz pebbles in Atoka (+ Winslow) sandstones in the Boston Mountains. The quartz pebbles in those conglomerates are similar to but smaller than the quartz pebbles present in the Caseyville sandstone and other conglomeratic sandstones of Pottsville age in Illinois, Kentucky, and West Virginia. No similar pebbles have been noted in the Atoka sandstones south of the Boston Mountains, however. It seems probable, therefore, that the source of the pebbles and associated sediments in the lower part of the Atoka formation in the Boston Mountains lay far on the east and that the small size of the pebbles indicates greater distance of transportation than was necessary for the larger pebbles farther east. By inference it also appears probable that some of the sediments of the coal basin that lay south of the Boston Mountains were derived from that eastward source.

STRATIGRAPHIC UNITS SUITABLE FOR MAPPING AND CORRELATION

In general, the coal beds with their associated plant fossils are the most continuous recognizable horizons in the section, but exposures of the coal beds are rare except in areas where some of the coals have been mined extensively. Consequently, the coal beds are poor horizons at which to subdivide the section. The sandstone beds are the best exposed units in the section and constitute the best map units, but practically all of the sandstone beds are lenticular. The Hartshorne sandstone is the only individual sandstone bed that is continuous throughout the Arkansas coal field. Every individual sandstone bed in the McAlester shale, Savanna sandstone, and the lower part of the

[13] A. H. Purdue and H. D. Miser, "Eureka Springs-Harrison," *U. S. Geol. Survey Atlas Folio 202* (1916), p. 15.

[14] Carey Croneis, "Geology of the Arkansas Paleozoic Area," *Arkansas Geol. Survey Bull. 3* (1930), p. 89.

Boggy shale has been traced to some point where it either tapers out at the edge of a lens or grades laterally into shale. Thus, the map units are lenticular sandstone beds of variable areal extent and such coal beds as can be traced by virtue of exposures in mines and prospect pits. Exact correlations of the map units from one part of the area to another can be accomplished best by careful mapping of the overlapping sandstone lenses, checked by scattered exposures of recognizable plant-bearing horizons and coal beds.

CONCLUSIONS

In conclusion, it may be stated that the deposition of Pennsylvanian strata in the Arkansas coal field occurred in a basin: (1) that was being progressively warped downward and whose north margin migrated northward across the area but lay near the position of the Backbone anticline during most of early Atoka time; (2) that underwent minor deformation by compressive pressure from the south during the period of deposition; (3) that stood close to sea-level throughout the greater part of the time of deposition; (4) that were not subjected to invasions of marine waters of sufficient depth or duration to leave a perceptible record in the stratigraphic column; and (5) that received the bulk of the sediments under fluviatile conditions. In consequence of these and other conditions the area is characterized by: (1) northward thinning of the strata, part of which is due to progressive northward overlap at the base of the Atoka formation and part to northward thinning of individual beds; (2) a sharp change in the structural pattern along an east-west line which probably marks the zone of greatest change in thickness of the coal basin strata; (3) limited lateral extent of lithologic units; and (4) no apparent symmetry of recurrence of lithologic types in the stratigraphic column.

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OCCURRENCE AND ACCUMULATION OF OIL IN LAREDO DISTRICT, TEXAS[1]

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ABSTRACT

During the past few years the Laredo district of South Texas has come into prominence as one of the outstanding shallow oil-producing districts of the United States. The oil is recovered chiefly from shore-line sands of Jackson age, which occur at depths ranging from 160 to 3,500 feet. Accumulation of the oil therefore is in structures primarily of stratigraphic origin, that is, in buried shore-line sands. However, southeastward plunging folds, having axes approximately at right angles to the Jackson strand lines, and normal faults, with strikes oblique or transverse to the strand lines, are ordinarily either essential or important contributory factors in effecting accumulation, especially in the larger and more extensive fields.

INTRODUCTION

The Laredo district is located on the Mexican border, in the extreme southern part of Texas. It embraces an area 160 miles long, north and south, by 50 miles wide, and includes all or substantial portions of the counties of McMullen, Duval, Webb, Jim Hogg, Starr, and Zapata.

This section of South Texas is predominantly a sparsely settled ranch country, characterized by a monotonous expanse of low rolling hills and cuestas, densely covered with mesquite and chaparral.

Topographic relief attains an elevation of more than 900 feet in southeastern Webb County on the summit of the drainage divide between the Rio Grande and Nueces rivers. From this locality the surface slopes southward toward the Rio Grande, northward toward the Nueces River, and eastward toward the Gulf of Mexico.

Oil, in commercial quantity, was first discovered in the district at Mirando Valley, northeastern Zapata County, in April, 1921.

HISTORY OF DEVELOPMENT

The discovery well was located near the base of a prominent topographic scarp, a surface relief feature that later became widely known as the Reynosa Escarpment. Whatever the structural attributes of this scarp, it can not be denied that it was long a controlling factor in determining the trend of early exploration work.

[1] Read before the Association at Los Angeles, March 25, 1937. Manuscript received, September 6, 1937.

[2] Consulting geologist, 1015 Milam Building.

Many handicaps, however, plagued the efforts of the pioneer operators. The roads were rough and unimproved, water for drilling purposes was scarce, oil-well supply houses were distant, and pipe-line facilities were entirely lacking.

The earlier drilling operations were confined almost entirely to a narrow strip of country along the face of the escarpment, and out-post wells were located in about the same relation to that feature as the discovery well at Mirando Valley. These initial wildcatting activities resulted in the discovery of the Carolina-Texas field and led to the finding of the several "shoestring" pools extending south along the scarp from the present town of Mirando City.

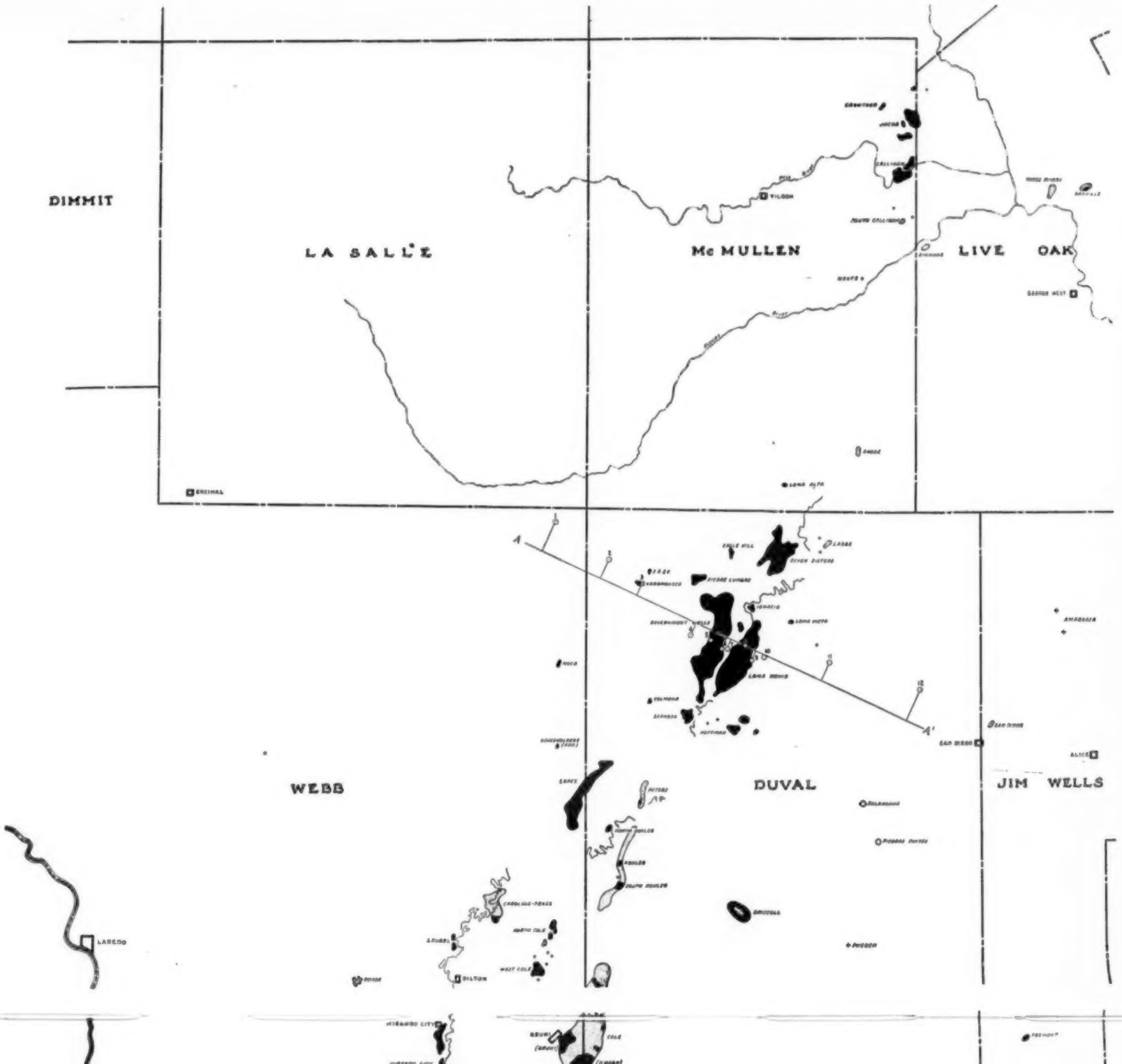
The Cole field, located north of Bruni, on the Webb-Duval County line, was discovered in July, 1924. It was the first field found east of the escarpment, and tended to attract attention to the possi-bilities of a much wider belt of country than that previously explored.

By January 1, 1930, twenty small oil fields and two or three gas fields had been opened. Subsequent to that time and especially since 1933 development has been rapid. Recently discovered fields include: North Government Wells, Loma Novio, Seven Sisters, Lopez, and the Bruni-O'Hern section of the Cole field.

At the present time (March 25, 1937) the district has thirty-five oil fields, approximately 3,450 producing oil wells and a daily aver-age production, subject to proration, of 60,000 barrels.

CLASSIFICATION OF FORMATIONS, LAREDO DISTRICT

Series	*Formation*		*Lithologic Character*	*Approximate Thickness in Feet*
Recent to Pleistocene	Reynosa		Caliche mantle	0–30
Pliocene	Goliad		Coarse gray sand and gravel, locally cemented with lime or silica, characteristically covered with caliche mantle; also beds of gray and mottled sticky clay	150
Miocene	Oakville		Coarse, brownish gray sand-stone interbedded with gray and buff clay and shale	250
Miocene and Oligocene(?)	Catahoula tuff	Chusa	Fine-textured tuffaceous clays	500
		Soledad	Coarse, brownish gray to green-ish sandstone and beds of vol-canic ash, containing igneous gravel and cobbles	600
		Fant	Principally volcanic tuff	100
	Frio		Light-colored, pea-green, pink and gray clays. Sandy clay and sandstone. Silicified wood	550



DIMMIT
LA SALLE
McMULLEN
LIVE OAK
WEBB
DUVAL
JIM WELLS
A
A'
LAREDO

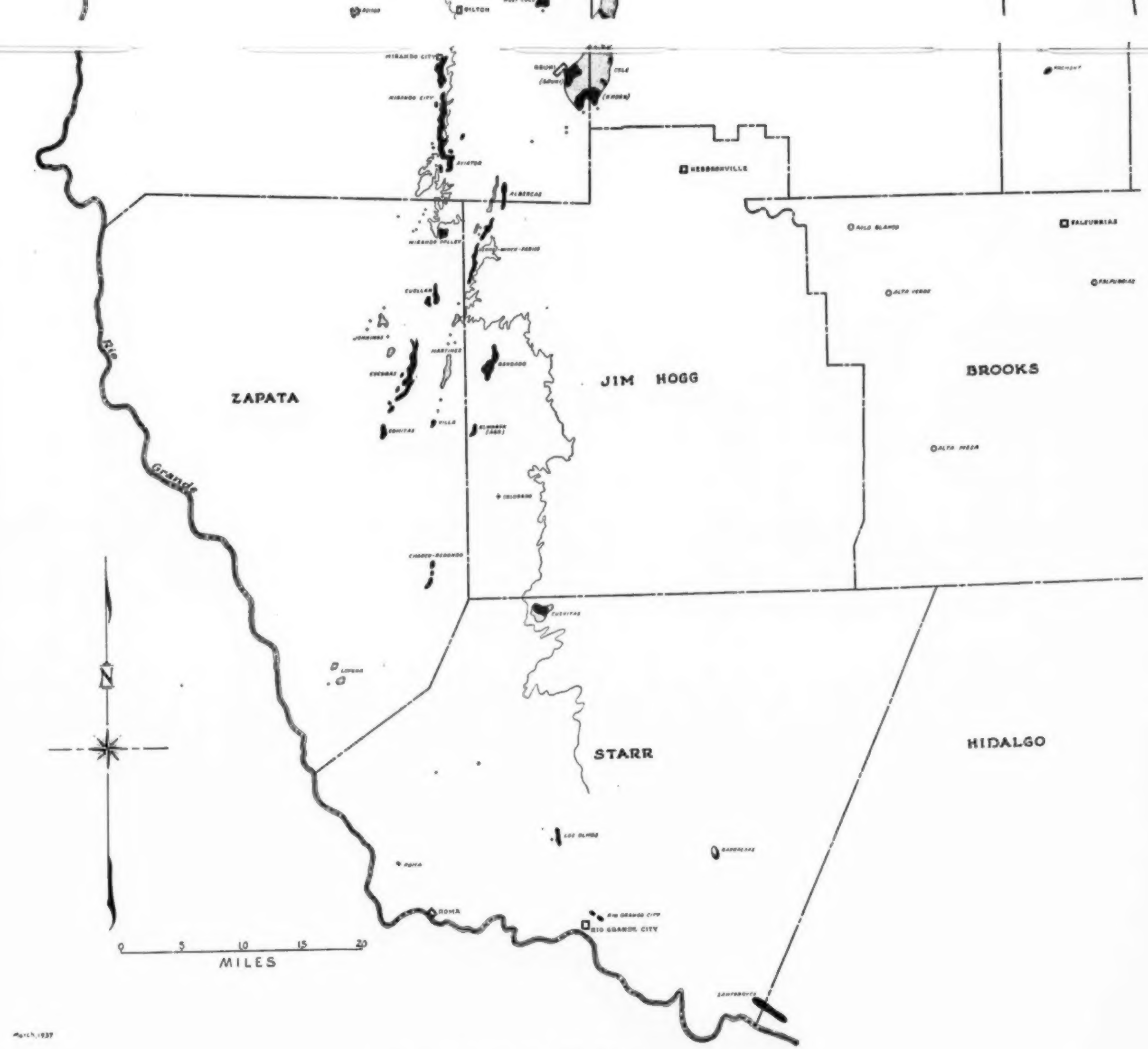


FIG. 1.—Oil and gas fields of Laredo district, Texas.

Series	*Formation*		*Lithologic Character*	*Approximate Thickness in Feet*
Eocene	Jackson	Whitsett	Dark green shale, green lignitic shale, gray sand and friable sandstone. Contains oyster shell beds; *Corbula* bed near top. Contains Cole sand, productive of oil and gas	300
		McElroy	Dark green shale, fossiliferous, gray-black shale, and beds of soft, gray, medium-grained sand. Contains Chernosky sand, Government Wells sand, Loma Novio sand, and Upper Mirando sand—most prolific oil-producing sands of district. Eastward, or down-dip, formation grades into brown to black fossiliferous marine shales, and thinning sand members, containing assemblage of *Foraminifera* headed by *Textularia hockleyensis*	800–850
		Caddell	Dark green to gray-black shales and beds of greenish gray glauconitic sand. Contains Lower Mirando sand; O'Hern sand at base. Down-dip grades to fossiliferous gray-black marine shales and thinning sands containing *Textularia dibollensis* and associated *Foraminifera*	100–150
	Cockfield		Greenish gray to gray-black micaceous shales and lenses or beds of fine to medium-grained greenish gray glauconitic sand. Pettus sand near top	200–275
	Yegua		Gray, brownish gray or purplish shales with beds and lenses of gray sand. Contains Bruni sand, also producing sands in Carolina-Texas field	560–930
	Cook Mountain		Gray to black shale and micaceous sandy shale and sand. Contains sands showing oil and gas	875
	Mount Selman		Brown and blue shale, lignitic shale, and brown to brownish gray sand. Queen City member contains Lopena gas sand	1,500

GENERAL STRATIGRAPHY

Surface rocks in the Laredo area include formations ranging in age from Eocene to Pleistocene. All formations consist of clastic and

pyroclastic sediments, composed chiefly of vari-colored clay and shale, volcanic ash and tuff, sand and sandstone.

Most of the sediments above the producing sands are of non-marine origin and contain no paleontologic markers. Thickness of formations must therefore be determined largely on the basis of lithology.

PRODUCING HORIZONS

JACKSON FORMATION

The principal oil-producing sands of the district belong to the Jackson group. As already indicated, this group is divided into three units of formational rank: the Whitsett (Fayette) at the top; the McElroy (Hockley) in the middle; and the Caddell (Diboll) at the base. All three formations contain oil-producing sands. These are locally designated or identified as follows: Cole sand; Chernosky sand; Government Wells sand; Loma Novio sand; Mirando sand, and O'Hern sand. All are similar in general character—gray to greenish gray in color, of medium-sized, well rounded grains—and are commonly unconsolidated. Depths to the producing sands vary in most of the fields from 750 to 2,950 feet.

Cole sand.—The Cole sand is a field name applied to the first sand encountered in the Jackson. Stratigraphically it is a lenticular sand zone in the Whitsett formation. Where productive its members ordinarily vary in thickness from 10 to 20 feet. It produces principally gas in the Cole field, but oil in the Randado and Eagle Hill fields, and in several scattered localities throughout the district.

Chernosky sand.—The Chernosky sand occurs in the upper part of the McElroy formation. It produces oil in the eastern part of the Seven Sisters field of northern Duval County. Its average thickness is 20 feet in the productive area.

Government Wells sand.—The Government Wells sand occurs just below the middle of the McElroy formation. It is one of the thickest and most prolific producing sands of the district. Individual oil-bearing sand members range from 10 to 35 feet in thickness, although the sand zone is much thicker. It produces oil in the Government Wells, Sarnosa, Seven Sisters, and Hoffman fields.

Loma Novio sand.—The Loma Novio sand occurs approximately 130 feet below the top of the Government Wells zone. The average thickness of the oil-producing part of this sand is between 12 and 20 feet. It is productive of oil and gas in the Loma Novio, Seven Sisters, and Hoffman fields.

Mirando sand.—The Mirando sand occurs near the base of the

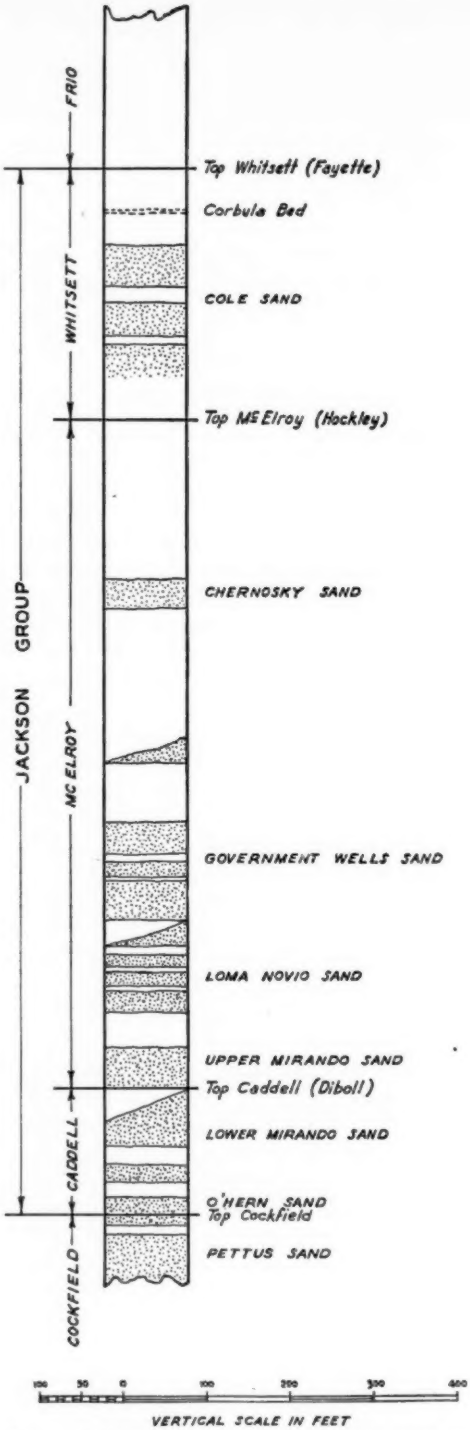


FIG. 2.—Relative positions of producing sands in Jackson formation, Laredo district, Texas.

McElroy formation. Sands occurring in the Caddell formation are also often classified as Mirando. This sand zone is generally characterized by associated beds of lignite and lignitic shales. Individual members ordinarily range in thickness from 15 to 25 feet. It is productive of oil and gas in the Lopez, West Cole, Albercas, Mirando City, Aviator, Cuellar, Escobas, Comitas, and numerous smaller fields.

O'Hern sand.—The O'Hern sand is at the base of the Caddell formation, and may possibly be upper Cockfield in age. It is productive of oil in the O'Hern extension of the Cole field in southeastern Webb County.

All of these producing sands are more or less lenticular in shape, are elongate in a north or northeasterly direction, and, where productive, almost invariably wedge out abruptly on the west or up-dip side.

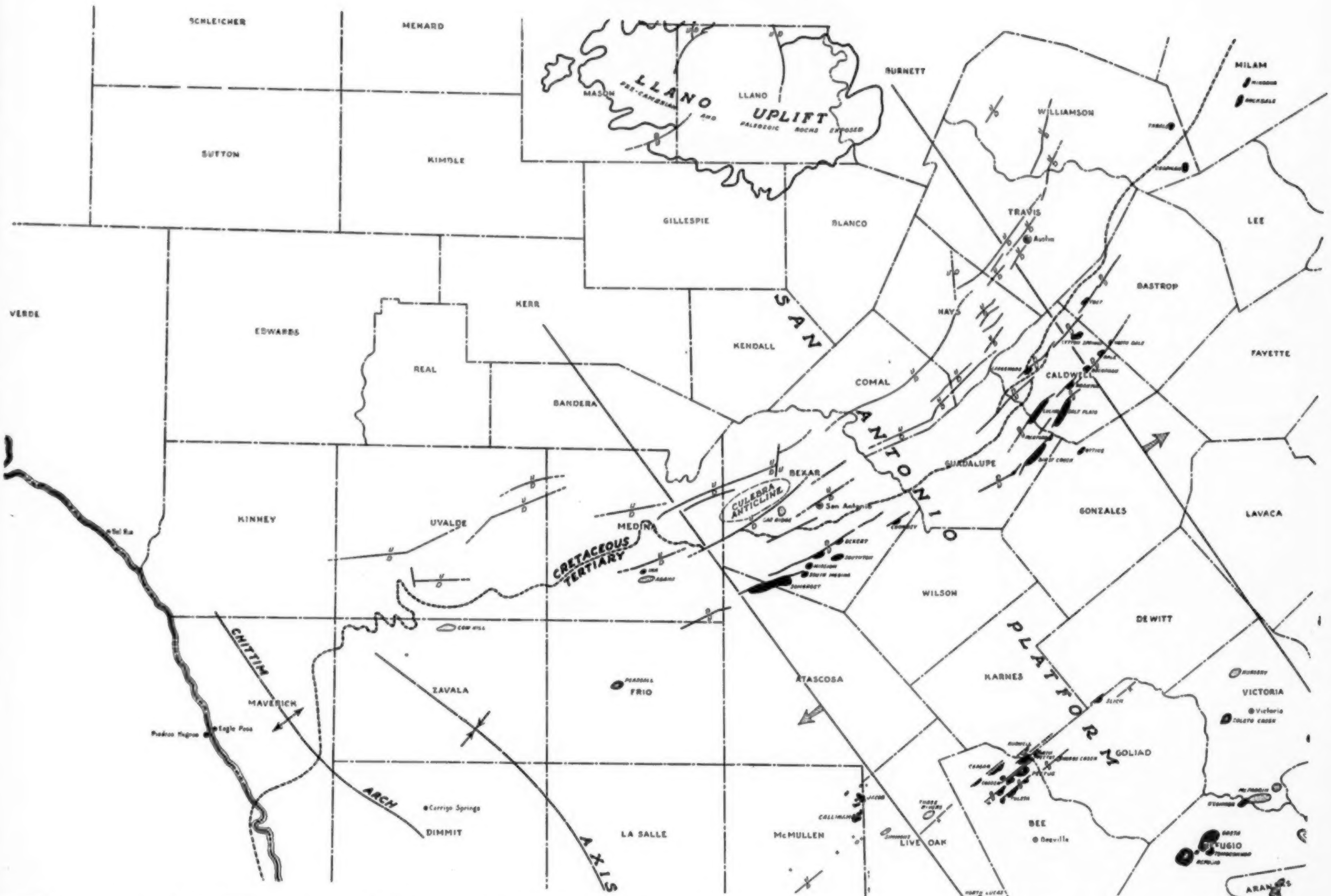
Oil produced from the sands ordinarily ranges in gravity from 20° to 24° Bé. It is estimated the average ultimate recovery will be approximately 650 barrels of oil per acre-foot of sand, and the ultimate yield per acre for most of the fields will range from 5,000 to 12,000 barrels, although individual leases may produce as high as 17,500 barrels per acre.

PRODUCING SANDS IN OTHER FORMATIONS

Approximately 95 per cent of the 90,000,000 barrels of oil produced to date (March 25, 1937) from the shallow fields of the Laredo district has been from sands belonging to the Jackson formation. This may be due largely to the fact that previously only a limited amount of deep drilling had been done.

The 3,400-foot producing sand at Bruni, in the Cole field, located on a closed anticlinal structure, is Yegua in age. The 2,600-foot sand in the Carolina-Texas field is also Yegua in age. Other scattered production has been found in the Yegua, but the quantity of oil produced in the district from this formation has not yet been large. Oil has recently been produced on salt domes and faulted structures in the eastern part of the territory in the Cockfield and Yegua formations, as well as the Jackson.

Gas and some oil have been encountered in the Cook Mountain and Mount Selman formations in the Carolina-Texas field of Webb County and at Roma in Starr County. Commercial gas production is found in the Queen City member of the Mount Selman formation in the Lopena field in southern Zapata County.


SCHLEICHER
MENARD
SUTTON
KIMBLE
LLANO
MASON
LLANO UPLIFT
PRE-CAMBRIAN AND PALEOZOIC ROCKS EXPOSED
BURNETT
MILAM
WILLIAMSON
TRAVIS
Austin
LEE
GILLESPIE
BLANCO
BASTROP
VERDE
EDWARDS
KERR
KENDALL
HAYS
FAYETTE
REAL
COMAL
CALDWELL
BANDERA
SAN ANTONIO PLATFORM
GUADALUPE
BEXAR
CULEBRA ANTICLINE
San Antonio
GONZALES
LAVACA
KINNEY
UVALDE
MEDINA
CRETACEOUS
TERTIARY
WILSON
DE WITT
CHITTIM ARCH
MAVERICK
Eagle Pass
Piedras Negras
ZAVALA
FRIO
ATASCOSA
KARNES
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Victoria
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DIMMIT
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McMULLEN
LIVE OAK
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Beeville
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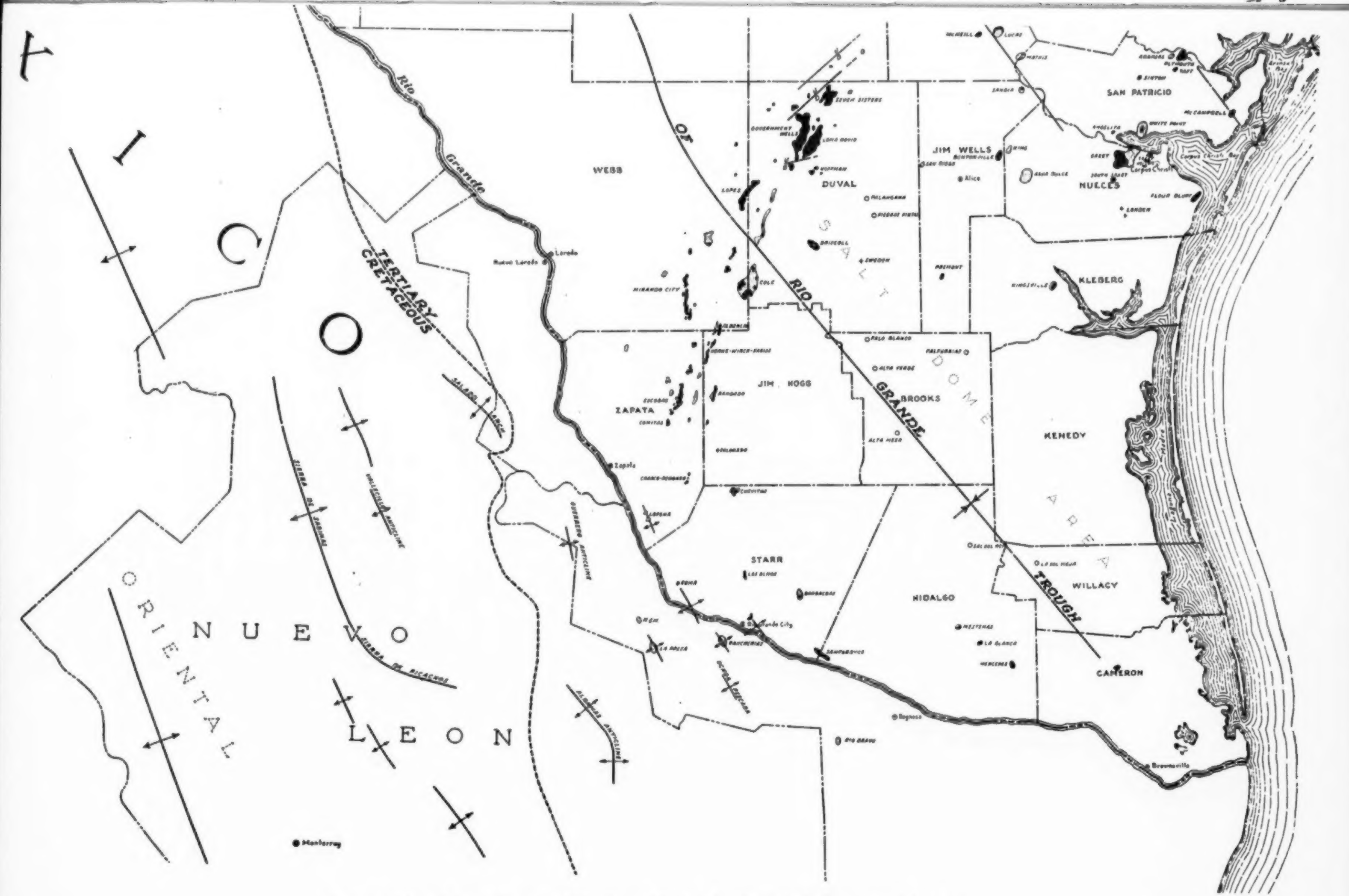


FIG. 3.—Map of South Texas and Northeast Mexico showing principal structural features.

REGIONAL STRUCTURAL FEATURES

Before undertaking a more detailed discussion of the nature of the occurrence and accumulation of the oil in the Laredo district, it is desirable to review the salient structural features of South Texas and Northeast Mexico. These include: (1) the Llano uplift, (2) the Balcones fault zone, (3) the San Antonio platform, (4) the Rio Grande trough, and (5) the Sierra Madre belt of folds.

The Llano uplift is a large domal structure in Central Texas. On its crest are exposed rocks of pre-Cambrian and Paleozoic age. The axial trends of the principal folds in these older rocks are northwest and southeast.

The Balcones fault zone comprises a complex system of faults which partly encircle the uplift on the east, southeast, and south sides, at a radial distance of approximately 75 miles. The principal faults of this system are downthrown on the southeast.

The San Antonio platform is a name assigned by the writer to the broad plateau-like structural divide that extends southeastward from the Llano uplift and is recognizable as far southeast as northern Refugio County. It is approximately 70 miles in width and separates the southwestern part of the Houston salt-dome basin from the Rio Grande trough.

The Rio Grande trough (sometimes called the Nueces geosyncline) is situated between the San Antonio platform on the northeast and the large anticlinal folds bordering the front ranges of the Sierra Madre Mountains of northern Mexico. The oil fields of the Laredo district are situated in this broad, southeastward-plunging structural trough.

JACKSON SEDIMENTATION

Conditions which have been very largely instrumental in effecting the accumulation of the oil in the Jackson sands are closely allied with the processes of sedimentation and the stratigraphic arrangement of the Jackson formations. A brief discussion of these subjects is therefore included.

Essentially the present coastal plain is the emerged or elevated part of the continental shelf on which the entire section of Cenozoic sediments was laid down. During the history of this period of sedimentation there have occurred repeated transgressions and regressions of marine waters. Naturally the invading sea tended to advance faster, to become deeper, and to remain longer in the basins than on the regional uplifts. In consequence, formations are ordinarily thicker

and more fully preserved in the central parts of the basins or troughs than on the uplifts.

The rocks of Jackson age are exposed at the surface in the Laredo district along a narrow, irregular belt, only a few miles west of the producing oil fields. This outcrop, which represents the beveled edges of the gulfward-dipping formations, extends northward across the Rio Grande trough, thence in a northeasterly direction over the San Antonio platform, and farther northeastward across the lower part of the East Texas Embayment, its trend roughly conforming with the present curvature of the Gulf Coast line. The regional dip is toward the gulf at an average rate of 100 feet per mile.

Surface investigation of the exposed rocks reveals certain pertinent variations in the facies of the sediments and in the lithologic character of the formations.

In the central part of the Rio Grande trough, the exposures comprise non-fossiliferous sediments almost wholly of continental, lagoonal, or littoral origin. Traced northeastward the general aspect of the outcropping beds gradually changes.

In the valleys of the Frio and Atascosa rivers in northeastern McMullen and southeastern Atascosa counties the outcrop is composed of fossiliferous shales, oyster beds, lenses or masses of loosely consolidated sands, and prominent scarp-forming sandstone members which possess characteristics clearly indicative of near-shore or shore-line conditions.

Farther northeast, along the San Antonio River, and well up on the San Antonio platform, the outcropping beds consist largely of brown fossiliferous shales and gray sandstones of definitely marine origin.

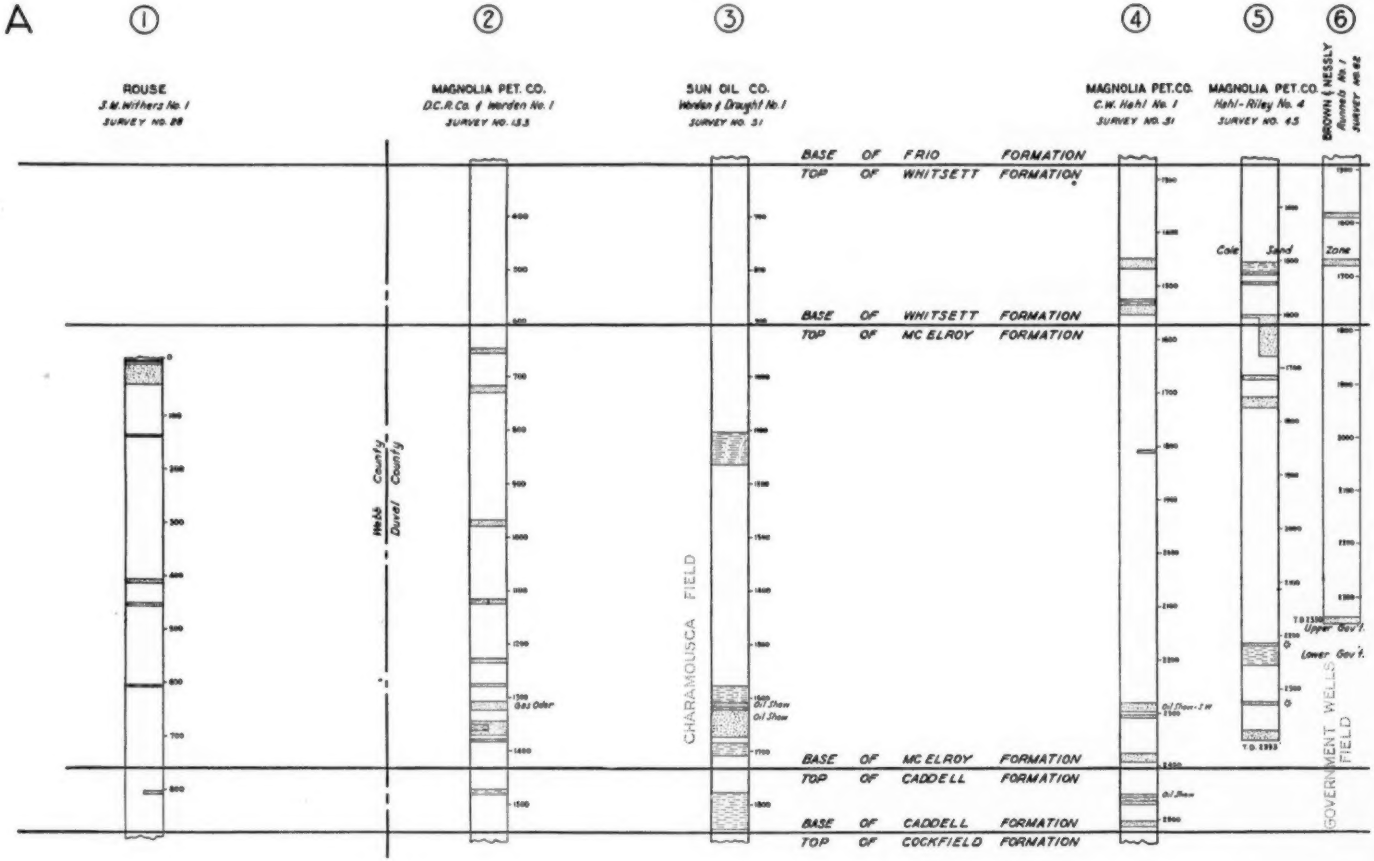
This distribution of rocks obviously evidences totally different environmental conditions of sedimentation. On the uplift, erosion has already attacked and removed all or large parts of the continental, lagoonal, or littoral deposits and has resulted in the exposure of the edges of the marine beds, although the former still remain undisturbed along the outcrop in the geosynclinal areas.

Similar stratigraphic variations may be noted at the outcrop along the Rio Grande, on the south limb of the trough.

From this study of the formations at the surface combined with evidence of subsurface data afforded by well logs, it appears that at the inception of the Jackson epoch a major part of the present Gulf Coastal plain was submerged. The distribution and orientation of the buried shore-line sand bodies and the trend of other coastwise deposits indicate that the strand line at that time was located not

STRATIGRAPHIC SECTION OF JACKSON FORMATIONS ACROSS NORTHERN DUVAL COUNTY, TEXAS

W.N.W. TO E.S.E.



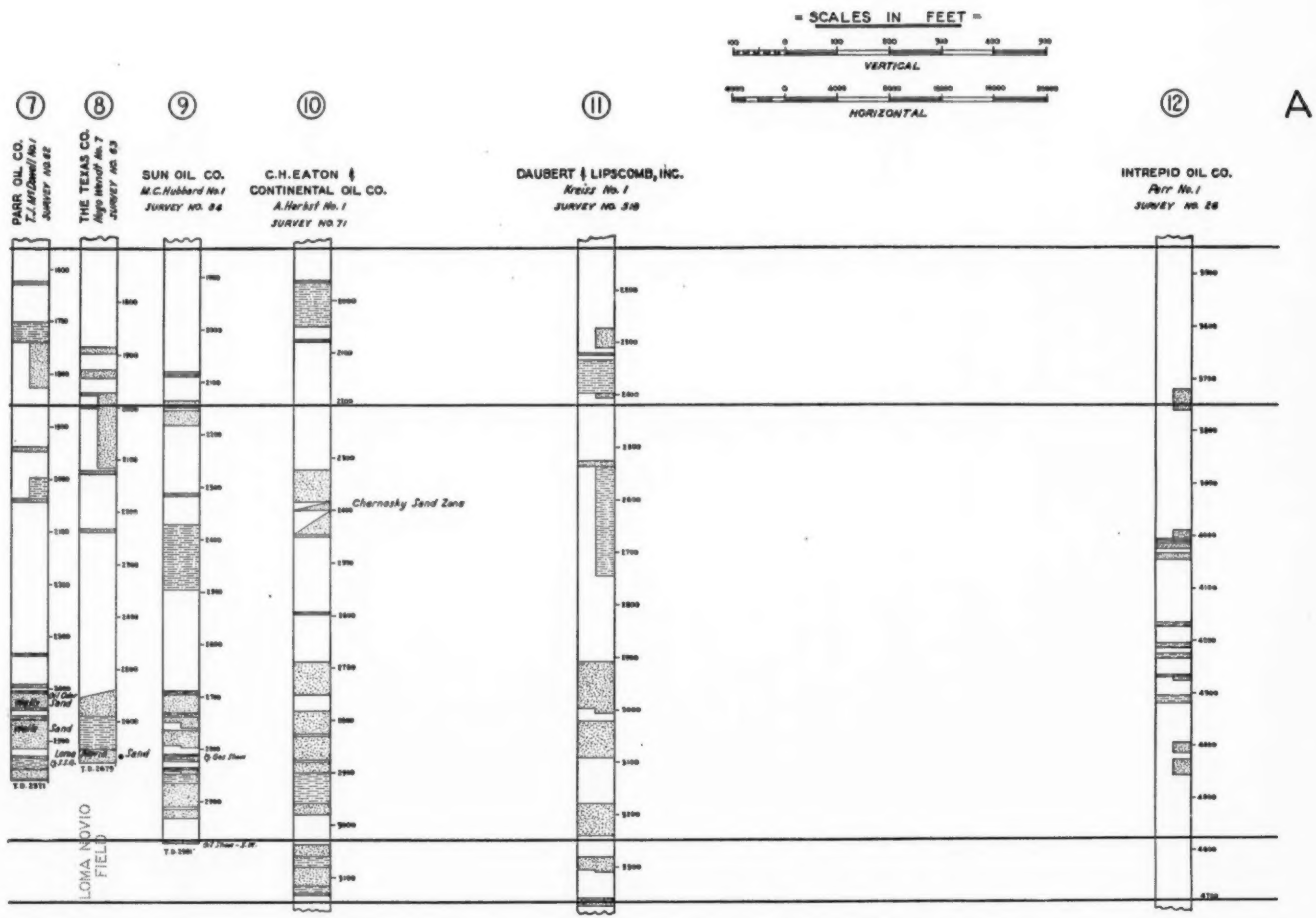


Fig. 4.—Stratigraphic section of Jackson formations across northern Duval Count y, Texas.

far from the present position of the northwestern corner of Duval County, and that its curvature conformed very closely to that of the present Gulf Coast line, although its extent was obviously of wider scope.

Numerous beds of lignite, lignitic shale, and clay persist in the lower part of the Jackson, which leads to the conclusion that the coastal area of that time was low and bordered by extensive swamps and lagoons.

Rhythmic transgressions and regressions of the sea continued throughout the period of Jackson sedimentation, evidenced by the interwedging of marine and non-marine sediments, as the strand line moved haltingly back and forth over a belt of territory 20 miles in width. Much of the time the Laredo area was slowly subsiding, although the rate of subsidence was variable. It was this combination of circumstances prevailing in the Rio Grande trough that tended to bury more or less *in situ* the shore-line sands and barrier beaches that then rimmed the shores. In essentially this same manner the O'Hern, Mirando, Loma Novio, Government Wells, Chernosky, and Cole sands were deposited and preserved.

After an early transgressive movement that inaugurated the Jackson epoch, during which the O'Hern and Lower Mirando sands were laid down, the strand line appears to have begun a slow retreat, moving progressively eastward, until near the middle of the Jackson period. Near the close of this regressive movement the Loma Novio, Government Wells, and Chernosky sand members were deposited. The sea again advanced landward several miles near the end of the middle Jackson, but apparently withdrew rapidly as the Jackson epoch came to a close. During this latter movement the lenses of sand and sandy shale forming the Cole sand zone of the upper Jackson or Whitsett formation were deposited.

The stratigraphic section (Fig. 4) of the Jackson group of formations (*AA'*, Fig. 1), prepared from well logs, extends from the outcrop in northeastern Webb County, across the Government Wells district to eastern Duval County, and discloses how the respective producing sands wedge out up-dip and are replaced by shale or clay members immediately west of the productive areas. The sands are ordinarily traceable, however, for many miles along the depositional strike, and several separate producing oil fields may be located along the same strand line. Eastward the sands grade into sandy shale and become marine in character.

LOCAL STRUCTURE

It has been pointed out that the occurrence of the oil in the Laredo district is chiefly in sands of Jackson age, and accumulation of the oil is primarily in stratigraphic traps; nevertheless, adequate recognition must be given to certain structural agencies which are either essential or important contributory factors in effecting accumulation, especially in the larger and more extensive fields (Fig. 5).

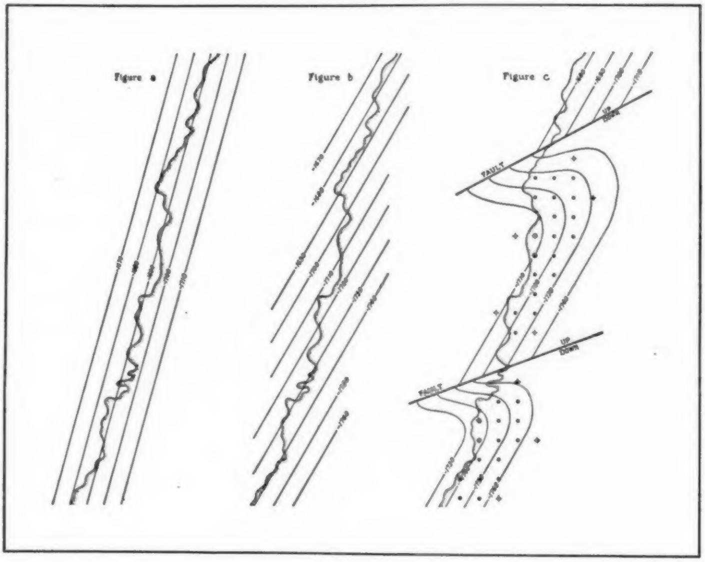


FIG. 5.—Stages in development of Government Wells structures, Duval County, Texas: (a) depositional trend of shoreward edge of shore-line sand lens, showing how contours originally paralleled this strand line; (b) effect of subsequent subsidence along axis of Rio Grande trough. Contours, oblique to original direction, reflect southward inclination of strand line caused by subsidence; (c) structural effect of faulting, and manner and position in which oil and gas accumulate.

In the northern part of the district, in northern Duval and McMullen counties, faulting appears to be the dominant structural influence. The faults strike from N. 40° E. to nearly east and intersect the Jackson strand lines which trend from N. 15° E. to N. 25° E. at intervals of 3–10 miles. Most of the master faults are downthrown on the southeast sides, but are locally accompanied by compensating faults downthrown on the northwest, thus forming narrow grabens.

In effect, these faults produce oblique or transverse syncline-like depressions across the strand lines and form the north closure on the structures in the Government Wells district.

Since the individual faults vary in magnitude of throw, in direction of strike, and in distance apart, it is at once apparent that the resultant deformations, combined with the normal irregularity of the sand deposits along the buried shore lines, produce structures of variable size, shape, and degree of productivity.

In the southern part of the district, southeastward-plunging folds approximately parallel with the lines of folding in northeastern Mexico and with axes oblique or transverse to the Jackson strand lines afford the principal agency leading to the localization of oil along the wedge edges of the respective sand members. Where the structural nose is broad and dips are inappreciable, the oil becomes distributed along the marginal limits of the sands, forming shoestring pools, as at Mirando City or Escobas. Where the folds or noses are more pronounced, the fields tend to be wider and are ordinarily oval or rounded as in the Carolina-Texas or Cole fields.

Immediately bordering the Rio Grande on the south limb of the trough, the Jackson shore-line sands either occur at shallow depth or are exposed at the surface. Accumulation of oil and gas in this border strip is on anticlinal folds, and oil is produced principally from sands other than Jackson in age.

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OROGENY OF THE URALS[1]

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ABSTRACT

The present Urals are bordered on the west by a belt of Permian and Carboniferous sediments thrown into long, gentle north and south trending folds. East of this, there is a zone of overthrusts—the older beds pushed westward, over the younger, in an intricate pattern, the amount of dip increasing eastward. Next come the central ridges made up of metamorphic Cambrian and pre-Cambrian rocks mingled with a great variety of basic and acid intrusions. The whole eastern slope is but a partly deciphered maze of sediments, green schists, igenous rocks, *et cetera*. Among them, the basic massif of Nijni Tagil and north of there, together with the Djabyk granitic massif and its northern extension west of Alapaevsk, are prominent. The Djabyk is considered to be a batholith emplaced as a culmination of the main orogenic phase. A considerable part of the Uralian geology in the east is concealed by Tertiary and later sediments. The grain of the formations is longitudinal, with the regions of Kara-Tau and Ufaley as marked exceptions. The structure of the central metamorphic ridges is predominantly sharply anticlinal.

The Uralian geosyncline, apparently a rift zone between the Russian and Tobolsk shields, had at least one pre-Ordovician orogenic cycle. Existence of a comparatively shallow Ordovician trough of deposition, from Mugodjary to Novaya Zemlya, is well established. Maximum post-Ordovician submergence occurred in Middle Devonian; another submergence took place in Lower and Middle Carboniferous. Tectonic forces, probably connected with the Taconic, Caledonian, and Acadian revolutions, acted on the geosyncline, especially on its middle and southern parts. There were numerous minor disturbances intervening. The main orogenic phase took place in the Permian, persisting into the Triassic. The resulting post-Permian Urals were eroded to their batholithic core, during the later Triassic. The Jurassic and Cretaceous again saw a widespread sea transgression which reached its maximum in Lower Tertiary. The time of rise of the present Urals is as yet unknown. The latest known disturbances are post-Pleistocene.

The Permian disturbance was expressed in a wedge-like orogeny, with the main compressive stress coming from the east. This produced the belt of easterly dips in the zone of overthrusts. A belt of westerly dips runs along the line Alapaevsk-Chelyabinsk, then swings into the Ural River Valley, toward Orsk. One variation of the wedge theory is that the whole of the wedge is included between these two zones of inward dips, with the batholith offset in the direction of the stress (asymmetrical). Another variation is that the Djabyk occupies a central position, and there should be another belt of westerly dips, hidden under the Tertiary sediments of Western Siberia. Gravimetric measurements in that region reveal alternating longitudinal zones of positive and negative anomalies similar to those farther west.

Because of the heterogeneous character of the Uralian geosyncline, no competent beds were deposited in wide areas, and the deforming stresses were transmitted through the basement complex. Thus a zone of underthrusts was formed in the River Belaya loop. Thrust faulting was followed by block faulting. Subsequent stresses were of non-compressive character. The mid-Ural strike-slip fault, with the amount of displacement up to 35 miles, is one of the latest adjustments to these stresses.

Oil was found in Permian strata, west of the zone of overthrusts.

[1] Manuscript received, August 20, 1937.

[2] Geologist, The Ohio Oil Company. The writer is greatly indebted to Professor C. M. Nevin, of Cornell University, for his help in preparation of the manuscript and map.

The Urals, an interior meridional mountain system, have long interested geologists. Because of their situation, away from any sea

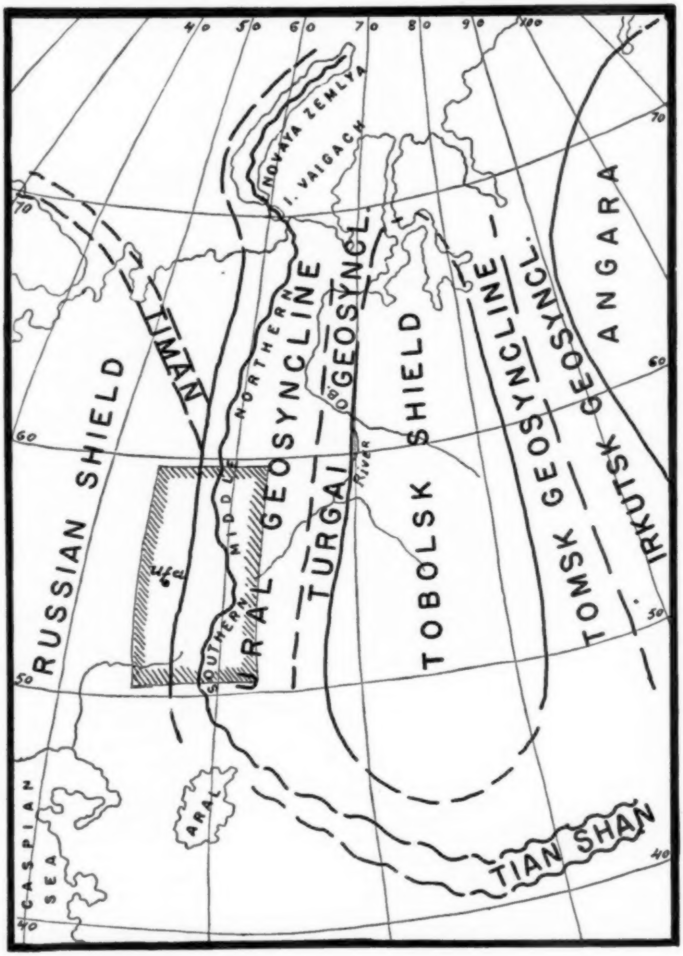


FIG. 1.—Map of Uralian system.

coast, the deciphering of their geologic history and structure should go far toward probing the validity of certain orogenic laws and principles derived from the study of other mountains. Unfortunately,

the Urals have remained (and to a considerable extent still remain) one of the geologic enigmas. Murchison made the greatest single contribution to the study of the Urals, in connection with his classic work on the establishment of the Permian epoch (1).[3] Since his time, and especially during the last 10 years, much field work has been carried on by Russian geologists, and many reports have been published. Since these are scattered through numerous scientific Soviet periodicals, and since they are in Russian with only occasional abstracts in English, German, or French, they are of small value to a non-Russian reader. The purpose of this paper is to bring out and discuss the major factors of the Uralian orogeny, in the light of these new data. Its scope is limited chiefly to the Paleozoic of the Middle and Southern Urals. The appended map is redrawn from the only modern geologic map of the Urals (3). Several important changes have been made, in accordance with new data, and some major fault zones are indicated, for the first time. At its best, this map gives only a general idea of the regional geology, which is especially true for most of the eastern slope, and also for the River Belaya loop, south of the 55th parallel and east of Kara-Tau.

Viewed as a whole, the Uralian system forms, in its north-south course, three unequal arcs, all convex toward the west (Fig. 1). The northernmost arc is formed by the Pai-Khoi ridge, extending northwest from Konstantinov Kamen, then by the ridges of Vaigach Island, across the Yougorsky Straits, and by the northeast-trending body of Novaya Zemlya. The middle arc stretches from Konstantinov Kamen to Ufa Plateau. The Middle Urals proper comprise the southern half of this arc, south of the terminal moraine on Sosva-Losva watershed (60° North longitude). Morphologically and structurally the Middle and Northern Urals are a single unit, which allows generalization of conclusions derived from a study of the middle region and compensates for a scarcity of data on the north.

Near Sverdlovsk, the Urals lose their mountainous character, giving an impression of bending around the Ufa Plateau; then regain their height, and branch into the ridges of the Southern Urals, which make up the third arc—from the Ufa Plateau to Mugodjary. This southern belt differs distinctly from the rest of the Urals. It is characterized by several ridges, as against only one or two, in a few places three, main ridges farther north; hence its width reaches 90 miles, though the rest of the Urals nowhere surpasses 40 miles.

Von Bubnoff (2) has divided the Urals into six longitudinal zones,

[3] Numbers in parenthesis refer to list at end of article.

which, with certain corrections, hold true and give a graphic idea of the Uralian morphology.

From west to east, von Bubnoff's zones are as follows.

I. Sediments of the western slope, from younger to older
II. Crystalline schists ordinarily making up the watersheds. (The metamorphic suite of the Ural-Tau and northern central ridges.)
III. Deep-seated basic rocks (gabbro-diorites, dunites). In the Northern Urals they form a fairly united belt which is broken into smaller units of the Middle Urals, on both sides of Zone IV
IV. Basic effusives, tuffs, and contact-metamorphic sediments
V. Granites and gneisses
VI. Strongly folded, shattered, and injected sediments of the eastern border. This zone resembles Zone IV. Most of it is covered by Mesozoic-Tertiary deposits of the Siberian Plain

STRATIGRAPHY AND GEOLOGIC HISTORY

The history of the Urals is traceable down to the Ordovician; beyond that, it is largely guess-work. Accordingly the sequence above the Ordovician is considered first.

Composite Section in Zilair Region and West of It After Blokhin (32)

Permian. Top, red sandstones, conglomerates; marls and marly dolomites. Downward change to gypsum and to shales and conglomerates. Total thickness, more than 8,000 feet

Carboniferous. Total thickness about 3,300 feet

Upper. Dark gray to black, in many places marly limestones with siliceous intercalations. 600 feet

Middle. Brown-gray limestones, siliceous in their upper horizons. 750 feet

Lower. Gray and white, in many places dolomitic limestones, up 1,400 feet, underlain by dark gray tough limestones, intercalated with black chert. 500 feet

Upper Devonian. Gray to white, well stratified limestones and dolomites, maximum thickness 300 feet, underlain by dark, thin-bedded limestone and bituminous shales, 600 feet thick

Middle Devonian. Dark gray, marly limestone

Lower Devonian-Silurian. Gray to brown and red sandstones, coarse-grained to conglomeratic, commonly cross-bedded, with plant remains on top. 900–1,200 feet

Silurian-Ordovician. Sandstones; alternating gray dolomitic limestones and gray shales. 150 feet

Ordovician and older. Gray-green, ordinarily medium-grained sandstones and shales; mica-and-talc schists. Apparent thickness as great as 3,000 feet

Metamorphic series. Oldest formations represented by green-gray siliceous schists, and sandstones with veins of white quartz. The degree of metamorphism increases eastward

As contrasted with the foregoing, a section of the eastern slope is of interest.

Section of Eastern Slope Immediately East of the Ural-Tau, Tirlan Region. After Dingelshtedt (18)

Lower Carboniferous. 4,200 feet of limestones and dolomites, siliceous in lower horizons, underlain by 300 feet of calcareous conglomerates, and 300 feet of tuffaceous sandstones and conglomerates

Upper Devonian. 600 feet of diabases cover 300 feet of albitophyres overlying (from top to bottom) porphyrites, tuffaceous shales, and augite-porphyrites

Middle Devonian. 1,800 feet of (top to bottom) siliceous schists and jaspers, lime-

stones, albitophyre, plagioclase- and augite-porphyrites, and their tuffs; and siliceous schists and jaspers

LOWER DEVONIAN-UPPER SILURIAN. 1,200 feet of augite-and-plagioclase porphyrites and their tuffs overlying limestones and porphyrites

ORDOVICIAN-SILURIAN

Existence of an Ordovician sea-way to the Arctic ocean is indisputable. The lowest Ordovician sediments are of definitely shallow-to-continental character. In the basin of Djaksy-Karagal, there are more than 1,000 feet of tuffaceous schists, sandstones, conglomerates, and limestones of the Kuragan series where *Obolus appollinus*, *Lingula oblonga*, *Orthis caligramma*, and *Orthis testudinaria* were found; likewise there are 2,000 feet of schists, limestones, conglomerates, and sandstones with *Asaphidae*, *Phacopidae*, and *Lichaidae* in the Tirlan region. Micro-grained sandstones and schists of the barren Serebryanksy suite, and the overlying Vissim series are considered Ordovician, since they merge into the fauna-bearing Ordovician, west of Revda. Farther north, there are limestones and shales of Losva-Sosva with *Pentamerus oblongus*, and finally the Trilobite-Brachiopod limestones of the Yougorsky Straits (70° N.L.). This sea-way apparently deepened eastward, since sands and shales of the Ashinsky suite in the extreme west contain terrestrial plants and show ripple marks and traces of continental weathering; and there is an eastward increase of limestone, as well as of igneous activity which is completely absent in the west. The effusives of Djaksky-Karagal are chiefly porphyrites and albitophyres. Northwest of Orsk, along Sukaya Guberlya, bituminous graptolitic shales of Upper Ordovician intercalated with siliceous schists are found together with basic effusives cut by small ultra-basic intrusions altered to serpentine. Throughout the eastern slope, the metamorphism is both contact and regional; hence, its degree does not depend on the distance from the central ridge. In the west the metamorphism progressively decreases away from this ridge.

The Silurian is marked by an increase of cherts and limestones, which points to the onset of Devonian submergence. Siliceous shales with *Monograptus argenteus*, *M. nudus*, *M.. fimbriatus*, *Rastrites longispinus*, and *Climacograptus scalaris* attain a thickness of 2,000–2,500 feet in the Sakmara region, and 1,000 feet farther east. Radiolarian cherts also appear in the Sakmara region. However, the Silurian sea still retains its shallow character, at least locally, as shown by argillaceous limestones of the Zilair region, changing to a reef type on the west and north. Still farther north, there are bituminous limestones, west of Revda and southeast of the Ufaley region. Limestones

and dolomites become purer toward the north, and there is a marked domination of dolomitic facies throughout the west.

Volcanic activity increased in the Silurian. The outpouring of the porphyrites of Nijne-Tagil, and of the andesite-basaltic magmas of Losva, began then and continued in the Devonian. Graptolitic and siliceous shales of Djaksy change upward to basic effusives, tuffs, and limestone lenses with *Karpinskya conjugula* of the lower Devonian. The record of acid igneous activity is obscure. In several places, sand and conglomerates contain grains and pebbles of granite, *et cetera*, but the original age and character of the sources of these fragments are not clear.

The presence of conglomerates, local thickening of sands, lateral changes of facies, together with numerous unconformities—all suggest a series of pulsations and minor disturbances. The two great unconformities in the west and north, where Ashinsky and Serebryansky suites are overlain by Middle Devonian, are the most striking examples. There also is an angular unconformity between the Ordovician and Silurian of Mugojary, as well as several unconformities in the Djaksy-Karagal and Sakmara regions. A detailed study of Siluro-Devonian unconformities has been commenced, and much remains to be done in this field. The connection between these pulsations and the type of igneous activity is also obscure. However, it seems to be fairly well established that the Silurian-Devonian submergence was accompanied by intermittent basic outpouring.

Summing up, we see indications of land west of a shallow Ordovician geosyncline whose eastern border is unknown but must have lain beyond the 62nd meridian. The numerous unconformities are no doubt reflections of local adjustments which may have been tectonically connected with the Caledonian revolution, and with the contemporaneous disturbances along the broad arc connecting the Urals with northern Tian Shan (Fig. 1).

DEVONIAN

The aforementioned adjustments brought about a patchy Lower Devonian record in the north and west, and probable restriction of the geosyncline in those parts. The Lower Devonian is absent in the River Belaya loop and along the western contact of the Serebryansky series of Choussovaya, and north of it. There is also a wide break in the Sosva-Losva region, farther north, where diabase porphyrites of Siluro-Devonian transition are directly overlain by Middle Devonian. Though this last break may well be caused by structural movements, the continental character of the Ashinsky and Serebryansky suggests

a depositional break, and rise of a western welt or chain, in connection with the submergence farther east.

In contrast to the north and west, the region east of the Belaya fault zone contains a continuous Siluro-Devonian record. Throughout the east, the Lower Devonian shows continuous submergence and widespread basic flows. The resulting abundance of green schists makes Devonian correlation difficult. Siliceous schists, and particularly radiolarian cherts, are characteristic of the Lower Devonian. The latter are especially well developed near Orsk, where the following Devonian section is found.

DEVONIAN SECTION NEAR ORSK, FROM TOP TO BOTTOM. AFTER PETRENKO (25)

		Feet
Sandstones, conglomerates, subordinated schists and tuffites	up to	1,000
Shales, partly silicified		2,700
Green keratophyric tuffs		2,700
Clastic porphyritic tuffs, tuffo-breccias, limestone lenses	up to	3,000
Cherts, siliceous schists, subordinate porphyritic tuffs; diabases	up to	3,000

Sedimentary environment of these radiolarian cherts points to a rather moderate depth of deposition, as shown by the following section of Kazak-Chikkan, northwest of Orsk.

SECTION NORTHWEST OF ORSK FROM TOP TO BOTTOM. AFTER PETRENKO (25)

	Feet
Gray-green jaspers, fine-grained siliceous formations with flakes of chlorite	15
Porphyritic tuffs with epidote and zoicite	15
Green and dark, velvety jaspers	150–225
Brecciated tuffs with jasper pebbles	45
Multi-colored jaspers, some radiolarian	60–90
Dark red radiolarian jaspers; cracks filled with magnetite	60
Light-colored radiolarian jaspers	60
Red, quartzite-like jaspers	15–45
Diabase and felsitic porphyrites	15–30
Dark violet jaspers	6–15
Diabase	

The Middle Devonian witnessed the greatest sea transgression, with continuous volcanic activity and deposition of Upper Radiolarian cherts. Shallow-water facies dominate throughout the west, where local unrest caused the Ordovician beds of Ashinsky and Serebryansky to be covered by different horizons of Middle and even low Upper Devonian. General evidence here points to westward movement of the sea. Farther east, marine and igneous facies dominate, metamorphosed to green schists. With the onset of Upper Devonian emergence, the effusives become more acid (quartz albitophyres, *et cetera*). At the same time, a splitting-up of the geosyncline begins in the south, leading to a great variety of facies in the Upper Devonian and especially in the Carboniferous, and to the formation of a number of separate basins with their peculiar local fauna. In the north, a

Middle Devonian-Carboniferous section in the Sosva-Losva watershed reveals several minor disturbances, but no such change in the character of effusives as is present in the south.

SECTION IN SOSVA-LOSVA WATERSHED, FROM TOP TO BOTTOM. AFTER MASHKOVTZEV (28)

	Feet
LOWER CARBONIFEROUS. Sandy limestones alternating with shales. *Spirifer konincki* Dew.; *Productus scabricus* Mart.; *P. corrugatus* Dew.	240
Unconformity	
Fine limestone, sand cemented with calcium carbonate; marls	10
Various diabasic tuffs	350
Yellow-gray, massive limestone, stratified in upper horizons. *Spirifer tornacensi* Nal.; *Productus nodosocostatus* Nal.; *Orthotetes crenistria*	150
Unconformity	
Massive, gray to white limestone intercalated with basic effusives	180
Diabases and their tuffs	
UPPER DEVONIAN. Tough argillaceous limestones with abundant corals and brachiopods. *Spirifer aff. archiaci; Productus praelongus*	25
Graywacke sandstones, shales, conglomerates, and tuffs; lower horizons with limestone lenses containing plants	150
Diabases and tuffs; subordinated limestones. *Productus* cf. *murchisonianus; Spirifer* ex. gr. *verneuili*	2,200
Basic pillow lavas	1,500–2,000
Graywacke sandstones, shales, conglomerates; a few thin limestone beds	2,700
Basic effusives and their tuffs	1,500–2,000
MIDDLE DEVONIAN. Diabase tuffs, sandstones, shales, conglomerates	3,000–4,500
Unconformity	
SILURIAN-LOWER DEVONIAN. Diabase porphyrites	

The so-called Zilair suite—transition from Upper Devonian to Lower Carboniferous—reveals one of the most important sources of Devonian-Carboniferous sediments, as well as an evidence of "Acadian" disturbance. This series comprises sediments of variable thickness on both sides of the southern Ural-Tau: in the Tirlan region and south of Beloretzk, in the Zilair region; also on the east, between the Ural-Tau and Ural Valley. Conglomerates and coarse sands of this series contain grains of siliceous schists, Middle Devonian effusives, Lower Devonian red radiolarian cherts, abundance of fragments of Silurian-Devonian effusives, less common fragments of Ordovician, and clastic material from the metamorphic series of Ural-Tau. Hence the presence of a central metamorphic ridge, or of a chain of welts, in the Upper Devonian and Lower Carboniferous can be inferred with a great deal of certainty. In this connection, it is significant that though the Upper Devonian sediments on both sides of the present Ural-Tau are fairly similar, there is no trace of the Zilair suite farther west, where the sedimentary record is not obscured by igneous activity. This also strongly suggests a major central source of sediments.

Whether a similar central welt was raised in the north at the same time is not clear. The whole area east of the central metamorphic

ridge is badly broken by igneous activity, and the region west of it is marshy and inaccessible. However, local changes of the Upper Devonian undoubtedly reflect a time of general unrest.

CARBONIFEROUS

Beginning with the Carboniferous, it is expedient to consider the present eastern and western slopes separately, since there is marked similarity north and south. Only the great instability of Carboniferous time is a feature common to both slopes.

Throughout the east, the Upper Devonian emergence is culminated by deposition of Lower Carboniferous coal beds. They become more numerous and better developed away from the central ridge, which suggests a progressive uplift from the east. The coal-bearing formations have been metamorphosed in places to graphitic schists.

The Lower Carboniferous is best known from the Ural River Valley, between Kizil and Tanalyk.

LOWER CARBONIFEROUS SECTION, URAL RIVER VALLEY, BETWEEN KIZIL AND TANALYK, FROM TOP TO BOTTOM. AFTER LIBROVICH (11)

	Feet
KIZIL SERIES. Top, dark limestone, underlain by finely brecciated limestone and calcareous sandstone with grains of limestone, chert, feldspar, and basic effusives; bottom, conglomerates and basic lavas	600–900
Dark limestones with basic lavas and tuffs	750–900
Light-colored, tough limestone, commonly of reef type	1,000
Brown to dark limestone	1,000–1,200
Gray limestone	450–600
Dark limestones in many places substituted by basic and acid lavas and tuffs	450–600
BEREZOV SERIES. Basic and acid lavas and tuffs; tuffaceous, areno-argillaceous, sometimes coal-bearing conglomerates and limestones	300–900
Alternating basic (spilites, paleobasalts, diabases, augitic- and hornblende-porphyries) and acid (plagio-porphyries, trachitic- and quartz porphyries, felsites), and their tuffs	1,800–2,100

The last mentioned, "alternating basic and acid effusives," are very exceptional phenomena. Their detailed section, along Ural River, in the latitude of Lake Kultaban, follows.

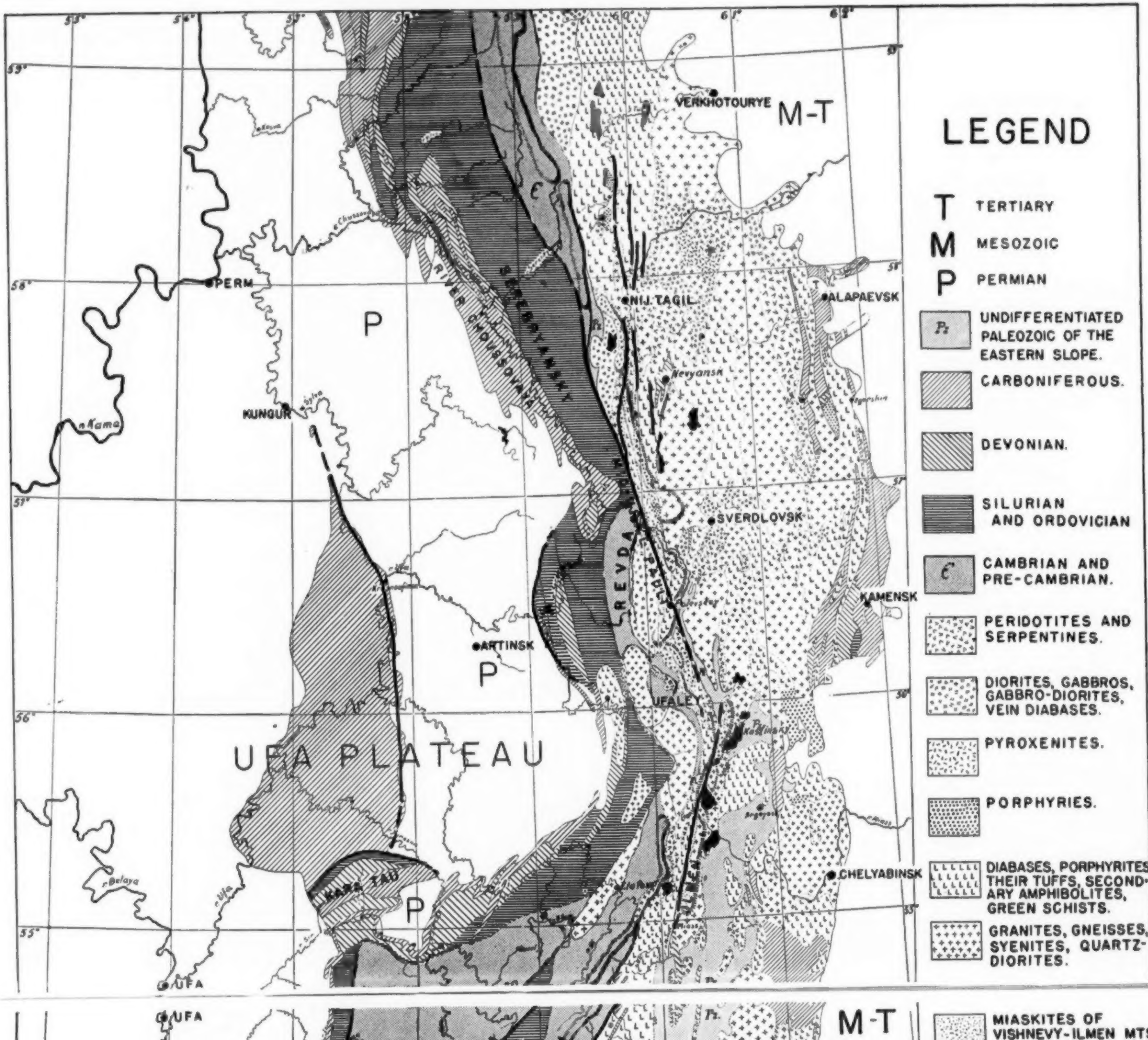
SECTION OF BERESOV BASIC AND ACID EFFUSIVES ALONG URAL RIVER IN LATITUDE OF LAKE KULTABAN, FROM TOP TO BOTTOM. AFTER LIBROVICH (11)

a. Top, fine-grained tuffo-conglomerates with fragments of albitized paleobasalt; remains of fauna with *Chonetes*. Bottom, green to black olivine paleobasalts, up to 150 feet

b. Trachitic porphyrites, changing upward to banded trachite-keratophyres. Southward change to basic effusives

c. Coarse tuffo-conglomerates with tuffaceous cement of basic composition and pebbles and boulders of diabase, olivine basalt, and limestone apparently derived from the underlying

d. Limestones, more than 250 feet thick; gray at the bottom with *Chometes comoides*, *Schellwienella crenistria;* changing upward to darker and well stratified facies, first rich, then poor in fauna; finally to sandy facies gradually enriched by basic tuffaceous material



LEGEND
T TERTIARY
M MESOZOIC
P PERMIAN
UNDIFFERENTIATED PALEOZOIC OF THE EASTERN SLOPE.
CARBONIFEROUS.
DEVONIAN.
SILURIAN AND ORDOVICIAN
CAMBRIAN AND PRE-CAMBRIAN.
PERIDOTITES AND SERPENTINES.
DIORITES, GABBROS, GABBRO-DIORITES, VEIN DIABASES.
PYROXENITES.
PORPHYRIES.
DIABASES, PORPHYRITES THEIR TUFFS, SECONDARY AMPHIBOLITES, GREEN SCHISTS.
GRANITES, GNEISSES, SYENITES, QUARTZ-DIORITES.
MIASKITES OF VISHNEVY-ILMEN MTS
VERKHOTOURYE
M-T
NIJ. TAGIL
ALAPAEVSK
PERM
KUNGUR
SVERDLOVSK
KAMENSK
ARTINSK
UFALEY
CHELYABINSK
UFA
UFA PLATEAU
P
SEREBRYANSKY
RIVER CHOUSSOVAYA
REVDA
KARA TAU

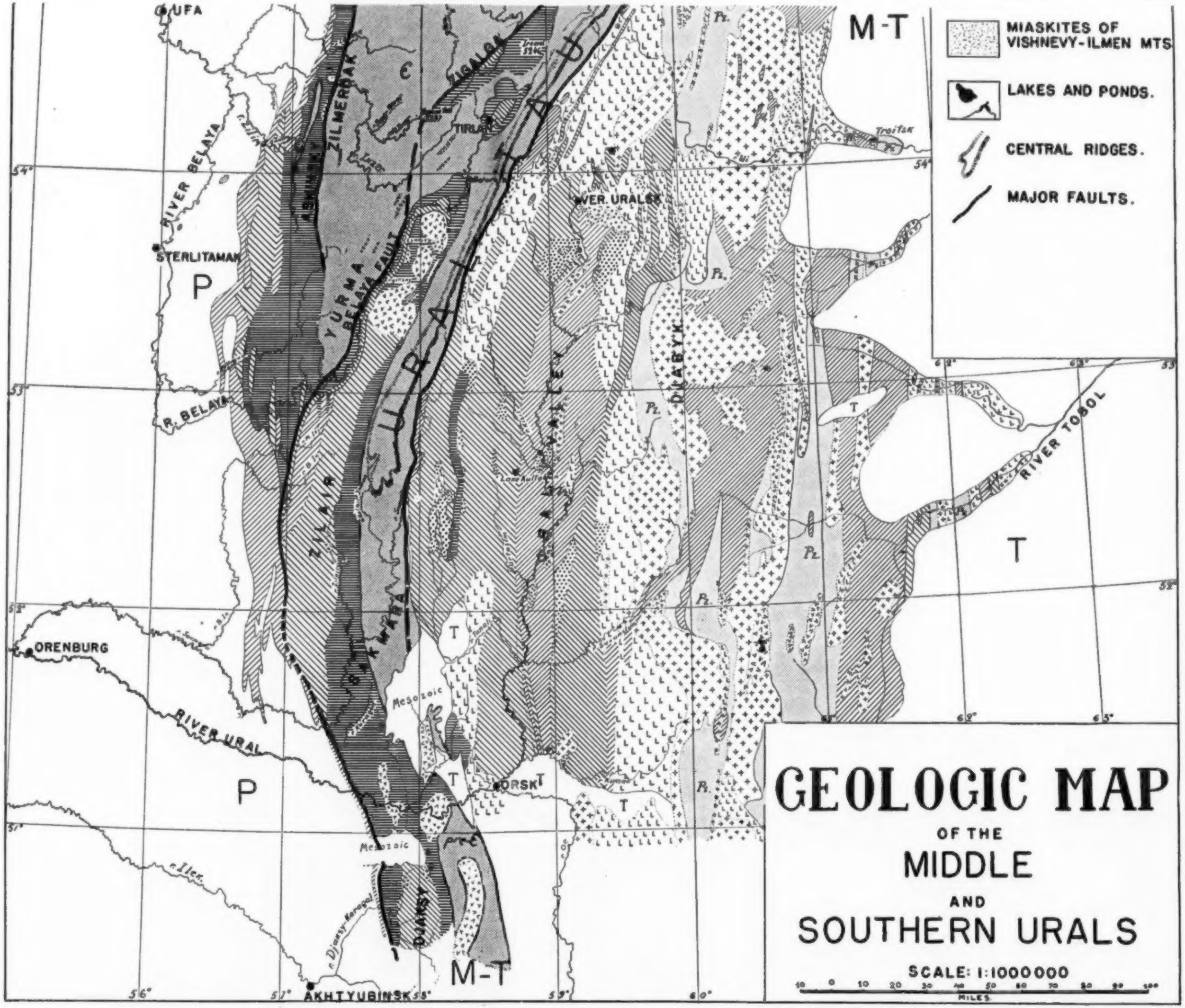

GEOLOGIC MAP
OF THE
MIDDLE
AND
SOUTHERN URALS
SCALE: 1:1000000
MILES
SYENITES, QUARTZ-DIORITES.
MIASKITES OF VISHNEVY-ILMEN MTS
LAKES AND PONDS.
CENTRAL RIDGES.
MAJOR FAULTS.
UFA
STERLITAMAK
RIVER BELAYA
R. BELAYA
ORENBURG
RIVER URAL
AKHTYUBINSK
ORSK
VER. URALSK
ZILMERDAK
YURMA
BELAYA FAULT
ZILAIR
URALTAU
DJABYK
DJAKSY
TIRLJAN
Troitzk
RIVER TOBOL
M-T
P
T
Mesozoic

FIG. 2

e. Alternating effusives. Red to brown trachite-keratophyric- and augite porphyries, felsites, plagioclase, and diabase porphyries, and their tuffs. Cut by veins of keratophyres, syenite-porphyries, diabase-porphyries. Veins apparently feeders of their respective effusive strata. Upper, basic section represented at places by green to black diabase porphyries and olivine paleobasalts, changing upward to brown, siliceous rock, then to strongly weathered ferruginous calcareous clays and shales intercalated by dark, stratified, arenaceous limestone.

The Lower Carboniferous emergence is not so strongly developed in the north, as is evidenced by the Losva-Sosva section (p. 1446) and by scant data still farther north. The emergence is followed by another submergence (Lower Carboniferous section on p. 1447), which never reached major proportions. Thick limestones and dolomites were deposited only in the central part of the geosyncline, with upper Lower Carboniferous, "Shartim," fauna found in widely separated places. On the east, only shallow-water facies overlie the coal-bearing series. This last submergence was not accompanied by any increase in volcanism. On the contrary, igneous activity markedly decreased at the end of the Lower Carboniferous—to resume with new violence with the onset of the main orogenic phase.

A Middle Carboniferous uplift is marked by numerous conglomeratic facies, with pebbles chiefly of Lower Carboniferous formations, and by brackish to continental deposits reflecting a further partition of the geosyncline into basins and lagoons. After this last emergence, the next marine record on the eastern slope is that of Cretaceous.

Carboniferous history of the western slope follows the general sequence traced in the east, with the exception of volcanic activity and final emergence. On the north, along Chussovaya and north of it, the coal beds marking the Lower Carboniferous emergence are covered by so-called "mountain" limestone, deposited during the following submergence. There is no coal in the south, where the emergence is reflected by shallow-water and ferruginous facies. The central welt, raised at the close of the Devonian, was apparently eroded at the close of the Lower Carboniferous, for the Zilair suite of Mt. Kraka (north of Zilair) is covered by sandstones intercalated with phyllites and corniferous beds containing small brachiopods. The eastern Middle and Upper Carboniferous emergence is marked in the west by a shallowing sea and local deposition and erosion.

There is a controversy on Upper Carboniferous-Permian correlation, and as to whether the Carboniferous deposition continued into the Permian, without a break. The prevailing opinion is that the Artinskian beds of the Lower Permian lie conformably on the Upper Carboniferous. Frederiks (37), on the other hand, considers the Artinskian as Middle Permian, with a break below it. The truth may

lie in between—at least as far as the Middle Urals are concerned. The aforementioned local erosion and deposition of the Upper Carboniferous might have continued into the Lower Permian, and thus created local unconformities observed by Frederiks. No Carboniferous-Permian break is found in the south, where marine Carboniferous limestones and dolomites of Inzer-Zilim are covered by shallow to continental Permian beds. In the far north, however, there is a break between Lower Carboniferous and Permian of the Pai-Khoi ridge (43).

The Upper Carboniferous of the Ufa Plateau indicates a shallowing sea, while the cupriferous Permian red-beds and conglomerates clearly show their eastern origin—the rising Urals. The gently folded Permian beds, and a belt of post-Artinskian overthrusts along the present western border of the Urals, are the only local expressions of the orogeny. Lack of data precludes its more exact dating, and any speculation as to its character, except for very general considerations. It was part of the great orogenic movement which created a long folded belt approximately coinciding with the aforementioned belt of Caledonian disturbances (44). In the Urals it was expressed by at least two main phases, divided by a short-lived Upper Permian sea ingression of the Artinskian trough, during which the brachiopod-bearing Kungur beds were deposited. In the Djaksy region, on the south, the second phase occurred during the Permian-Triassic transition (26). The folding of Permian beds also took place at that time.

POST-PALEOZOIC

Absence of Mesozoic and Tertiary sediments throughout the greater part of the Urals permits only a brief account of the post-Permian history—and that necessarily based on records in adjacent regions.

During the Triassic the whole of the Urals stood high and was being eroded, as is shown by continental beds in the west and by extensive deposits of bauxite and brown coal in the east. These conditions persisted into the Jurassic. Middle and Upper Jurassic are present in patches between the rivers Ural and Ilek. They lie unconformably in post-Kungur (Ufa) synclines, and also reflect a deformation subsequent to their deposition. Formations southeast of Orenburg testify to the presence of an Upper Jurassic embayment—a harbinger of Cretaceous sea transgression (38). Similarity of Upper Jurassic ammonite beds of the Northern Urals to those of Russia suggest a wide Upper Jurassic sea transgression in the north (2). An Upper Cretaceous sea-way west of the present Urals was connected

in the south with the contemporaneous eastern sea, as shown by marine Cretaceous between Sterlitamak and Orenburg; along the west course of the Ural River; and all along the eastern slope. By the Middle Cretaceous, the Urals were deeply eroded, and the sea advanced west: in the Sosva-Losva watershed, the Middle Cretaceous is found overlying the Upper Devonian, west of the 60th meridian. The submergence reached its maximum, in the east, in the Lower Tertiary, when the sea might have touched the line of the present central ridges. To what extent the subsequent emergence affected the western slope, and the character of the emergence itself, is not yet clear. There are peculiar latitudinal normal faults in the Djaksy region, affecting the whole vertical section, including the Paleogene. There also is evidence of a post-Pliocene uplift, farther north.

IGNEOUS ROCKS

As already shown, Devonian submergence was accompanied by an increase of basic intrusions which, in turn, became more acid as the Devonian-Carboniferous emergence progressed. Generally the coupling of submergent-basic and emergent-acid phases seems to hold true for the whole of the known history of the Urals—with a change from extrusions to intrusions in the Carboniferous. The peculiar "alternating" effusives of the Lower Carboniferous might have reflected an extreme instability. Basic intrusives continue to be important almost up to the time of main orogeny, since gabbro-pyroxenes are known to cut the whole section including the upper Lower Carboniferous. Therefore, they must have been of a later date; but not much later, for there are indications of increased acidity of intrusives with the progress of Carboniferous emergence. Hence it seems that the Devonian basic-acid cycle of extrusives was repeated in a Carboniferous basic-acid cycle of intrusives.

The basic-acid complex along the great Mid-Ural strike-slip fault, and in the Ufaley region, south of it, is too complicated to be deciphered at the present time. However, it is clear that the basic rocks were metamorphosed during the main orogeny, and their grain ordinarily follows the regional schistosity. This is not true for the most of the acid intrusions which culminated and followed the Carboniferous-Permian orogeny. Study of the Djabyk granitic massive is illuminating. The Djabyk is a part of the acid Zone V (p. 1442) which undoubtedly is a huge batholith, with the main body at various depths, and with offshoots injecting into and breaking through the crust. Flow structure of the Djabyk indicates its arrival after the orogeny was practically over. An approximately central position of

the whole batholith, with reference to the present eastern slope, seems to be well established by gravimetric measurements in the adjacent area of Western Siberia, covered by recent deposits. These measurements show alternating belts of positive and negative gravity anomalies, similar to those of the eastern slope of the Urals. This is additional evidence that the present eastern slope of the Urals is a mountain system eroded to its batholithic core.

The ultra-basic dunites, either original or metamorphosed to serpentine, may be a product of differentiation of basic magma,[4] which would relate these intrusions to the rest of the basic complex of the Urals. A "posthumous" igneous activity is suggested by diabase dikes cutting squarely across the grain of the formations. Their age is unknown, although there are some indications of their being post-Jurassic. Perhaps they have some connection with the similarly trending southern normal faults. These diabase dikes are in turn cut by pegmatities.

PRE-ORDOVICIAN

In several places, Ordovician conglomerates contain pebbles of metamorphic and igneous rocks, both basic and acid. This suggests at least one pre-Ordovician submergence-emergence cycle. No fossils definitely Cambrian have been found in the Urals, except for supposed structures of blue-green algae, similar to *Anomas* of Siberian Lower Cambrian, and also of something like *Archaeocyathus;* but the Pomorsky formation of the northern extension of the Urals in Novaya Zemlya is definitely Cambrian. The Cambrian and possibly pre-Cambrian age of the so-called Metamorphic suite of the Ural-Tau and northern central ridges has long been suspected; but only recent work in Tirlan, Beloretzk, and Belaya loop regions made possible a semblance of pre-Ordovician correlation.

Most of the barren series of the River Belaya loop have been considered Lower Devonian. But the Ordovician (Ashinsky) crops out along the east-west course of the Belaya; and since the regional dip is south, the northern formations must be older. Furthermore, iron ore, present in the dolomites of the Belaya loop, is absent in the Lower Devonian east of there, in the Beloretzk syncline, where it is found in older metamorphic formations. This again points to a much older age of the barren series. On the basis of work in the Inzer-Zilim basin, a sub-Ashinsky section is constructed.

[4] N. L. Bowen and J. F. Schairer, "The Problem of the Intrusion of Dunite in the Light of the Olivine Diagram," *Int. Geol. Congr. Rept. XVI Session, U.S.A.*, Vol. 1 (1933), pp. 391–96.

PRE-ORDOVICIAN SUB-ASHINSKY SECTION, INZER-ZILIM BASIN, FROM TOP TO BOTTOM. AFTER DINGELSHTEDT (36)

	Feet
ASHINSKY. Top, sandstones with carbonaceous inclusions	
Shales, in places micaceous or calcareous	
Thin-bedded sandstones interbedded with shale	
Conglomerates and sandstones	
Thin-bedded sandstones; shale. Ripple marks	
Base, arkosic sandstone with weathered feldspars	
Total thickness of the Ashinsky	3,000
Break	
MINYAR. Dolomites and limestones; flint. Forms similar to *Archaeocyathus, Etmophyllum, Epiphyton*	1,200
INZER. Shales and sandstones; glauconite sand; marls	2,400
SUB-INZER. Limestones and dolomites, ordinarily dark gray; apparently thin out eastward	
KATAV. Marls with dolomites and limestones in upper horizons. Total thickness of sub-Inzer and Katav	1,800
ZILMERDAK. Top, quartzitic sandstone; bottom, quartz-microcline sandstone and conglomerate; sandy and pure shales, some sericitic. Swash and ripple marks and mud cracks	4,500
Middle dolomites of Revet and Satka; limestones and shales	3,500
BAKAL. Shales and phyllites	2,000
ZIGALGA. Sandstones and quartzites	3,000
Lower phyllites and chloritic sandstone	5,000+
Metamorphosed basic effusives (amphibolites, *et cetera*)	1,000
YAMAN-TAU. Quartz-sericite, argillaceous and calcareous facies; conglomerates	3,000

On the basis of a stronger degree of metamorphism, the formations below Bakal are considered pre-Cambrian. The Zilmerdak series are tied up with quartz-microcline sandstones, *et cetera*, of Tirlan—thus a tentative correlation of the Ural-Tau formations is established. According to it, the whole Upper Cambrian of the northern Ural-Tau is eroded, which fits well into the picture of "Acadian" disturbance and subsequent erosion, bringing about the Zilair suite of clastic sediments. From the Tirlan sandstones down to amphibolites, the Ural-Tau section is fairly parallel with that in the west. The amphibolites of the northern Ural-Tau are underlain by the following section from top to bottom.

SECTION UNDERLYING AMPHIBOLITES OF NORTHERN URAL-TAU, FROM TOP TO BOTTOM

	Feet
Micaceous and chlorite-quartz schists (supposedly corresponding with the Yaman-Tau series)	up to 3,000
Green mica-chlorite-albite schists; conglomerates	2,000+
Micaceous quartzites	3,000
Mica-chlorite-quartz schists interbedded with feldspar-mica schists	15,000

The oldest rocks are present in the Sakmara-Orsk region, where the foregoing section is underlain by graphitic quartzites, micaceous albite-actinolite schists, and finally by green granite-glaucophane schists. In the Serebryansky region, the Metamorphic suite is represented chiefly by quartzites, quartzitic and siliceous schists, mica-chlorite and graphitic schists. Petrographically, it is similar to the

Vaigach Island (70° N.L.) series which are pre-Cambrian. The foregoing correlation is admittedly speculative. It is given here to emphasize the tremendous thickness of pre-Ordovician sediments (perhaps more than 30,000 feet) and their shallow-water to continental character.

MIGRATION OF THE GEOSYNCLINE

Considering the Uralian geosyncline geographically as well as historically, we may picture an ancient, north-south trending trough of deposition, with the old Tobolsk land of Suess in the east, and an unknown land on the west (Fig. 1). The character and the amount of pre-Ordovician sediments suggest either a narrow seaway bordering a welt, or a local source of sediments from welts raised by periodical disturbances. Swash and ripple marks on Zilmerdak sandstones are significant in this connection.

A lack of homogeneity in the geosyncline is noticeable as early as Ordovician. The geosyncline did not behave as a unit, but the adjustments within it were rather the sum of differential movements of its parts, both vertically and laterally. This heterogeneity perhaps was one of the factors of the apparent eastward migration of what may be called the most mobile zone of the geosyncline—the zone of the greatest igneous activity. Indeed, only a few diabase outcrops are found west of the Zilmerdak fault, while they progressively increase toward the east of it. The "Acadian" disturbance which brought a welt or a chain of welts along the present Ural-Tau, seems to have marked an epoch in the migration of the geosyncline. Since then, igneous activity has been largely confined to the present eastern slope, which at that time was the most active part of the geosyncline, with the old Ural-Tau as an important source of sediments. Additional Carboniferous sediments came from the old source on the east.

It was in this eastern belt that the main phase of Carboniferous-Permian orogeny took place, with its final batholithic intrusion, and its Triassic-Jurassic erosion. By the Cretaceous, the Uralian geosyncline had migrated definitely east, and the greatest Tertiary sea transgression did not extend west of the present central ridges. The eastern border of the Tertiary geosyncline is unknown. Finally, the Turgai geosyncline—whose eastern border runs roughly along the 70th meridian—may be the latest expression of eastward migration of the Uralian geosyncline (Fig. 1).

MAJOR FACTORS OF URALIAN OROGENY

Several major factors of Uralian orogeny are evident from the foregoing discussion.

1. The Ural zone has been a mobile belt of weakness, at least since pre-Cambrian.

2. During that period, several major adjustments have taken place, with numerous minor disturbances in between. Metamorphic and igneous pebbles in Ordovician conglomerates testify to at least one major previous disturbance. The records of "Acadian" and Carboniferous-Permian disturbances are much clearer; finally, there was a Tertiary major uplift. Minor disturbances are known to have occurred in post-Taconic and Caledonian times, and again in Triassic and Jurassic. The latest known adjustment is post-Pliocene.

3. A high degree of heterogeneity, especially in the southern parts of the geosyncline, prevented deposition of competent beds over wide areas. Therefore, deforming stresses could not have been transmitted over long distances, except through the basement complex.

4. A shifting of the zone of deformation is noticeable throughout the known geologic history of the Urals. The Carboniferous-Permian phase of the orogeny took place east of the locus of the "Acadian" disturbance. Finally, the Tertiary uplift was largely confined to the eastern zone of the geosyncline. A certain independence in the movements of the present eastern slope from those of the western slope is also suggested.

MAJOR STRUCTURAL FEATURES OF THE URALS

It is to be noted that an unknown part of the eastern zone of the Urals is covered by Tertiary and later sediments which conceal some of the major structural features. This is a great handicap to the study of Uralian tectonics, since this excludes data that might be decisive in formulating any hypothesis as to the nature of Uralian orogeny.

Longitudinal, north-south grain is the outstanding feature of the Urals. This, and the alternation of belts of positive and negative gravity anomalies, are the only certain features of the concealed eastern zone. A generally simpler structure of the Northern Urals, as compared with that of the Middle and Southern Urals, and a progressive decrease of metamorphism throughout the west, away from the central ridges, are also significant. The main features of the present eastern slope are long folds, chiefly asymmetrical, broken by thrust faults that can be traced for tens of miles; the whole cut by and intercalated with igneous rocks. Of the latter, the Djabyk granitic massive is the most important. As already stated, this is an extension of the granite-gneiss belt appearing from under the later sediments between Verkhotourye and Alapaevsk; but there are indications of a break in this belt of acid intrusion, in the region southwest of Chelyabinsk. In

this connection, it is significant that the Carboniferous strata, both in the Alapaevsk-Kamensk and Ural Valley regions, dip west, at 40°–60°; likewise, the axial planes of the northeast-trending eroded Devonian anticlines between Ver. Uralsk and Mt. Magnitnaya, south of it, dip west. Thus the line, Alapaevsk-Kamensk-Chelyabinsk, curving southwest through the Ural Valley, would mark a belt of easterly dips, nearly parallel with the curve of the central ridges. Western dips of Alapaevsk-Kamensk are incompatible with the assumption that the northern granite-gneisses are a continuation of the main body of the Djabyk batholith. In that case, the dips should be toward the east, marking the eastern slope of the batholith roof, even as the western dips of the Ural Valley mark its western slope. Hence, either the northern extension of the Djabyk lies east of Alapaevsk-Kamensk line, in which case the northern granite-gneisses are only an offshoot of the main body—or else the two sets of western dips were caused by other forces.

Farther west, the Metamorphic suite of the Ural-Tau is divided from the eastern complex by a sharp contact caused by a normal high-angle fault, up to 70°, apparently dying out toward the south. Sharp anticlinal structure of the Ural-Tau is evident in the Djaksy region, and can be traced throughout. Its arcuate trend must have been of early origin, as suggested by areal distribution of the Zilair suite of clastic sediments. The sharp and steep east-dipping contact of mid-Uralian Metamorphic suite is similar to that of the Ural-Tau. In the Northern Urals, the Metamorphic suite forms the central zone of the mountain system.

Thinning out of the Metamorphic suite along its western contact with the Serebryansky, and its raggedness opposite the Ufa Plateau, are not original features. The first is caused by a great strike-slip fault which, for lack of a better name, is here called the Mid-Ural fault. Its northeast side is displaced toward the northwest, a maximum of about 45 miles. This fault cuts obliquely across the regional grain, and is almost vertical, except for local deviations caused by varying character of the formations. It is definitely traceable as far as the Nij. Tagil region; farther northwest, progress of field work is handicapped by inaccessibility of the country. Evidence of continuance of this fault is found, however, in the upper courses of the eastern tributaries of Chussovaya, along the Serebryansky-Metamorphic suite contact. It is significant that, if projected still farther, this fault would appear at the branching of the Timan range. Since its zone of mylonitization 2 kilometers wide affects all the formations of the region, itself being cut only by gold-bearing quartz veins, it is

evident that the mid-Ural fault was one of the last major adjustments. The exceptional straightness of the fault trace corroborates this assumption, for any subsequent major folding stress would have disturbed this regularity. Parallelism of trends, west of the Revda massif, is a remnant of the original curvature of the Mid-Uralian equivalent of Ural-Tau.

Regions northeast and south of the Ufa Plateau are a striking exception to the rest of the Urals. The regional grain of the formations bends around the plateau, and the dips of all thrust planes are away from it. This is true both for the Ufaley region with its igneous-metamorphic complex, and for the overthrusts of Kara-Tau. Parallel east-west structures north of Tirlan may have been caused by the same stress that has brought about the Kara-Tau arcs. A southeastern stress, transmitted through the basement complex, must have caused the great underthrust of the region between the Zilmerdak and Zigalga faults, with its series of northeast-trending anticlines slightly overturned toward the east. However, the structure of this region appears to be more complex. A cross section (35) shows the eastern wing of the great syncline, west of the Yurma-Zigalga anticline, to be steeper than its western wing. The Zilmerdak fault plane is shown to dip east (35) at about 40°. The underthrust theory demands a much steeper, if not reverse, dip of the Zilmerdak fault, as well as a reversed symmetry of the major syncline. However, a certain amount of underthrust is undoubtedly present here.

A belt of overthrusts, fringing the western border of the Urals, is one of their most striking features. Their dips, along the western border of the middle and southern arcs, are ordinarily low-angle, and radial toward the center of the arc. The amount of horizontal movement is in many places large, surpassing 20 miles in the Chussovaya region. Overthrusting has produced very complicated structures, with repetitions of some horizons, and with some other horizons entirely missing. Generally speaking, the zone of overthrusts is narrower at the nodes of the arcs (Ufa Plateau, Djaksy). It is also to be noted that overthrusts are present in the Zilair and Djaksy regions, east of the southern extension of Belaya fault zone. There the dips of thrust planes progressively steepen toward the east.

The arcuate trend of overthrusts is repeated in block faulting. Besides the already mentioned Ural-Tau fault, the best known is the Belaya fault. Along the river Belaya, east of Yurma, a regional southern dip of the barren ancient formations brings progressively younger, from north to south, horizons in contact with Silurian of the Beloretzk syncline. The fault plane dips here to the east at about 45°.

It is apparently traceable toward the north, into the Yurezan syncline, east of the Zigalga ridge, and south, along the 57th meridian. It is undoubtedly connected with the east-dipping fault zone of Djaksy, and north of there. Directly opposite the Ufa Plateau, the structure of the Ilmen-Vishnevy Mountains is a good example of the tremendous strain to which this region has been subjected. A torque was produced along the Ilmen-Vishnevy line, with the result that the Ilmen anticline was overturned toward the west, while the Vishnevy anticline, in the north, was overturned toward the east (34). Both anticlines have a nepheline (miaskite) core.

Finally, Permian beds, west of the Urals, are thrown into long, gentle folds trending parallel with the orogenic belt. These are typical foreland folds; and they become more intense in the north, where a belt of so-called "Parma" fringes the Urals, north of the Timan. The Carboniferous island of the Ufa Plateau has a regional westerly dip of less than 2°, with a normal fault along its eastern border.

URALIAN OROGENY

The following suggestions are here advanced to explain the Uralian orogeny.

1. The Uralian geosyncline was an expression of a rift zone between the Tobolsk and Russian shields. This zone apparently widened from north to south, and was underlain by parallel minor rifts. Indeed, the Uralian sedimentation suggests a narrow trough of deposition, with two lateral sources of sediments. The heterogeneity of the geosyncline warrants the assumption of additional minor rifts. Tensional stresses, which brought about the original trough, also created two lateral zones of weakness, on either side. Subsequent compressional stresses then would create two dominating chains of welts along the borders of the geosyncline; the western of these early welts was the source of clastic sediments which now form the metamorphic suite of the central ridges, and the barren series of the Belaya loop.

2. Subsequent adjustment to these tensional and compressional stresses was expressed in a two-sided, wedge-like orogeny, with the present Urals marking the western boundary of the wedge. Only in this way may the apparent independence of vertical movements of the present eastern and western slopes of the Urals, the lateral shifting of their orogenic phases, and the major structural features of their western slope, be satisfactorily explained. Under this hypothesis, the present eastern slope would be the middle belt of the wedge; as such, it would be deformed and uplifted as a unit, independently of the sides. The western zone, on the other hand, would not act as a

unit. It would eventually be broken into a series of block faults, with easterly dip of the fault planes progressively decreasing away from the center. This, indeed, seems to be the fact. If this is true, there must be an eastern expression of the wedge, somewhere in the Ob River basin (Fig. 1). A zone of westerly dips may well be concealed under the Tertiary and later sediments of Western Siberia; but the absence there of anything like the Urals testifies to an extreme asymmetry of the Uralian orogeny, and a predominant eastern stress. Indeed, evidence of such a stress is manifest throughout the Urals. The asymmetry of the wedge, in turn, may be explained by epeirogenic movements of the two shields. During the main orogenic phase or phases, the Tobolsk shield might have stood higher relative to the Russian shield. This would have shifted the zone of the easiest relief toward the west, and would have made the whole western zone a locus of maximum deformation.

On the other hand, the aforementioned belt of westerly dips, along the line, Alapaevsk-Chelyabinsk-Ural Valley, suggests an alternative hypothesis, under which the whole of the wedge would lie west of that line, with the batholith emplaced east of it, asymmetrically with reference to the orogenic belt. The weight of evidence, however, favors the first assumption, that is, the batholith emplaced between the two sides of a wedge. With the exception of a slight retardation during the Carboniferous uplift of its western part, adjustments of the present eastern slope were those of a unit rather than of two parts separated by the line of westerly dips. Likewise, there is no change in the degree of metamorphism on either side of this line.

Along Chussovaya, and north of there, the older sediments are thrust over the gently folded Artinsky and Kungur beds. This fixes the time of these overthrusts as post-Middle Permian, and subsequent to the folding. In the Djaksy region, the main phase of overthrusts is thought to have occurred during the transition to the Triassic. The beginning of the wedge structure, however, must have taken place much earlier—at least as early as "Acadian" time, when a chain of belts arose along the present Ural-Tau. Folding continued thereafter, with the general eastern stress regionally resolved along directions from northeast to southeast. Faulting followed, with the steeper dips immediately west of the Ural-Tau formed first; subsequent stresses brought about a westward widening of the zone of overthrusts, with progressively decreasing dips, until the Permian-Triassic overthrusts were formed. But the orogeny did not stop there, as the evidence of Jurassic disturbance shows. Furthermore, the mid-Ural fault must have been formed still later, perhaps during the Tertiary uplift.

Therefore, some of the major stresses came after the westernmost overthrusts had been produced. Since these later stresses did not create new overthrusts, nor appreciably affect the old zone of overthrusts, it is evident that they must have been of non-compressive character. The trend of the mid-Ural fault suggests a couple acting about the Ufa Plateau, in post-Paleozoic time. The Ufa Plateau itself must have been a part of the Ural geosyncline—up to Upper Carboniferous time, when there is evidence of its uplift. The Ufa Plateau fault must have been one of the latest adjustments to tensional stresses. This fault presumably is younger than the mid-Ural fault, or else the couple that made the whole area northeast of the mid-Ural fault line slide along the edge of the shield, toward the Timan, would have produced the same effect along the Ufa Plateau fault line. Finally, evidence of these later stresses, again in conjunction with the Alapaevsk-Ural Valley belt of westerly dips, suggests another variation of the wedge theory. Some of these stresses might have been relieved by producing a "posthumous" wedge, whose western border coincided with that of the old wedge, and whose eastern border ran along the Alapaevsk-Ural Valley line of westerly dips.

In conclusion it may be said that, whatever its origin, the Ural geosyncline has all the major characteristics of a typical geosyncline, except for a bilateral source of its sediments. Uralian orogeny, likewise, followed the general pattern that has given the other great mountain systems of the world.

OIL IN THE URALS

The immense mineral wealth of the Urals undoubtedly includes vast stores of oil. Both the sedimentation and the structure of their western slope, especially the region west of the overthrust zone, are favorable to formation and storage of oil. There is the geosyncline persisting into the Permian; there is considerable thickness of bituminous shales and limestones; and there are the storing sands. Numerous unconformities might easily have furnished the cap rock. Finally the structure of the region—long foreland folds—is also favorable.

Prospecting for the Ural oil is still in its initial stage. By 1935 oil was found in two widely separated regions: near Sterlitamak, and at Chussov Gorodok, northeast of Perm. Both those places are situated west of the overthrust zone. The producing horizons are reported as Permian.

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EVALUATION OF PETROLEUM IN OIL SANDS BY ITS INDEX OF REFRACTION[1]

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ABSTRACT

The index of refraction of petroleum is believed to be a useful criterion of its commercial value. Methods of determining the refractive index of crude oils with the Abbé refractometer are described and previously published data on the relation between refractive index and specific gravity of crude oils and distillation fractions are discussed. Available data on Venezuelan crudes are shown graphically and demonstrate an approximate linear relation between refractive index and specific gravity (or A.P.I. gravity).

Refractive index has some advantages over specific gravity as a means of grading oils. It is particularly adapted to the preliminary evaluation of oil in sands encountered during drilling because only a minute quantity of oil is needed for an accurate determination. Finally, it is a valuable aid in identifying oils of similar provenance and in correlating oil-bearing horizons between different wells.

INTRODUCTION

The commercial value of petroleum, in so far as it depends on physical and chemical properties, can be determined accurately only through a complex series of laboratory tests, analyses, and assay distillations. Obviously, it is not at all times practicable to make such tests, nor is it practicable to make them on very small quantities of oil. Simpler if less accurate methods of evaluating an oil have, therefore, been sought, and through custom and convenience specific gravity (or A.P.I. gravity) has become the most widely used standard for preliminary grading. Light oils (high A.P.I. gravity) yield a high percentage of gasoline, while heavy oils (low A.P.I. gravity) show relatively greater proportions of gas oil, heavy lubricating fractions, and fuel-oil residuum.

The purpose of the writer is to call attention to another method for the preliminary evaluation of crude oils which has certain advantages over the specific-gravity method when the only oil available for testing is that present in cores or rock samples. The *index of refraction* of an oil is believed to be at least as good a criterion of its commercial quality as is specific gravity. It is less subject to modifying influences such as the presence of emulsified water or foreign matter

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in suspension. It is easy to determine accurately and it has the outstanding advantage that determinations can be made satisfactorily on much smaller quantities of oil than are ordinarily required for specific-gravity determinations. For this last reason, the refractive-index method is particularly adapted to the preliminary evaluation of oil sands during drilling and before actual production tests are made.

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SIGNIFICANCE OF REFRACTIVE INDEX

The index of refraction of a substance is the ratio of the velocity of light in air to the velocity of light in the substance. For example, the index of refraction of water at 20°C. is 1.333. In other words, the velocity of light in air is 1.333 times the velocity of light in water.

$$\frac{\text{velocity of light in air}}{\text{velocity of light in water}} = 1.333$$

The velocity of light in petroleum oils is even less than in water and the indices of refraction of common petroleum crudes range from about 1.400 to about 1.600.

In general, the refractive index of petroleum decreases with increasing content of volatile constituents (lighter fractions) and increases with increasing proportions of fractions with high boiling points. Thus the refractive index of ordinary gasoline is about 1.41, of ordinary kerosene about 1.44, of light lubricating oils about 1.48, and of asphaltic residues as high as 1.600. This relation approximately parallels that of the specific gravity of these fractions.

The refractive index of any particular substance varies with its density (Lorents-Lorenz formula) but the refractive indices of *different* substances may show no relation to their respective densities. Since petroleum oil is a mixture of a number of different compounds, there might seem to be little basis for assuming a theoretical relationship between density and refractive index. However, experimental

data have shown that the refractive indices of many of the individual constituents of petroleum increase in approximately the same order as their boiling points and, as mentioned already, it is also known that the density of petroleum oils decreases as the proportion of volatile constituents increases (compare Table V). Therefore, a general correspondence between refractive index and density of petroleum is to be expected and empirical data confirm a rough linear relation between the two.

METHOD OF DETERMINING THE REFRACTIVE INDEX OF PETROLEUM

The method of determining the refractive index of petroleum oils is relatively simple and rapid. All of these oils fall within the range of the common Abbé refractometer, the manipulation of which is entirely mechanical. Only a drop or two of oil is necessary and the index of refraction is read directly off the instrument scale without any need for calculation. The whole operation, in the case of light oils which may be read by transmitted light, takes only a few seconds. The instrument is sturdy and portable, and retails at a price of about $250.[3]

With an Abbé type of instrument equipped with a rear window in the prism housing, determinations may be made by either transmitted or reflected light. Readings by transmitted light are easier and probably more accurate but can be made only with the lighter-colored oils. The procedure is briefly as follows. The instrument is set up before a window where good daylight is available. A drop or two of oil is placed on the fixed prism, the other prism is rotated into position and clamped, and the telescope tube is swung around to a convenient angle. Light is focused on the prism opening from the mirror and the index arm is unclamped and moved to a position where the line dividing the light and dark portions of the field (border line of total reflection) approximately bisects the cross hairs of the telescope. The compensator drum (for neutralizing dispersion effects) is then adjusted until the dividing line just begins to show a blue border, the index arm is clamped, and the line is made to exactly bisect the cross hairs by means of the fine adjustment screw (Fig. 1 A). The index of refraction is then read directly through the magnifying lens on the index arm.

In the darker (and usually heavier) petroleum oils, sufficient light

[3] The writer uses an Abbé refractometer manufactured by Bausch & Lomb Optical Company, Rochester, New York. Refractometers of the Abbé type are also manufactured by a number of other optical companies. It is important that the type of Abbé refractometer used have a rear window in the prism housing.

can not be passed through the oil film on the fixed prism to give a satisfactory reading. It is then necessary to resort to reflected light. With the instrument in reading position the prism box shutter is swung back so that light enters through the rear window of the prism housing, the index arm is moved approximately into place, and an attempt is made to accurately locate the border line of total reflection in the field. In some moderately light-colored oils a fairly sharp line

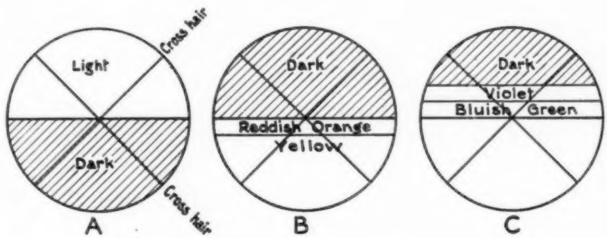

FIG. 1.—Abbé refractometer field with instrument set in position for reading. *A*, transmitted light; *B* and *C*, reflected light.

comparable to that seen by transmitted light may be observed and a very accurate index determination can be made. However, for the majority of dark petroleum oils, the instrument fails to show a distinct line in either of the positions of dispersion compensation. In such cases the compensator drum should be rotated until the spectrum colors which appear in the field reach maximum strength and from these spectrum colors it is then generally possible to approximate the position of the border line of total reflection as explained in the following paragraph.

There are two positions on the compensator drum where the dispersion colors are at a maximum. In one position (Fig. 1 B) the line

of total reflection is bordered on the lower side (side toward observer) by an orange band followed by a yellow band. In the other position (Fig. 1 C) the line of total reflection is bordered on its upper side (side away from observer) by a bluish green band followed by a violet band. The bluish green band forms the strongest contrast to the background of the field and for that reason may be most readily and most accurately identified. The instrument is therefore adjusted until the lower (side toward observer) edge of this bluish green band bisects the cross hairs and the reading is then made. In case the band is broad and indistinct it is advisable to take an average of ten readings. The results, while not as exact as those by transmitted light, will be found essentially correct.

Variations in temperature influence to a considerable extent the refractive index of petroleum oils. Many Abbé refractometers, including the Bausch and Lomb model, are equipped with a water-circulating jacket for maintaining constant temperature. However, this is unnecessary if the working-room temperature is fairly constant and if a temperature correction is applied.

It is useful to keep a record of the dispersion data obtained for various oils during the course of refractive-index determinations.

SOME PREVIOUS DATA ON THE REFRACTIVE INDEX OF PETROLEUM OILS

A number of investigators have secured data on the refractive indices of petroleum oils and their distillation products, and on the relation between refractive indices and specific gravities. The writer has not had an opportunity to search the literature thoroughly and the data given below are by no means exhaustive.[4]

Rittman and Egloff[5] (1915) found a regular and proportional increase in refractive index with increasing specific gravity for the "naphtha" and "kerosene" fractions of more than a dozen American and Russian crude petroleum oils. Hamor and Padgett[6] (1920) state that

> the refractive index, determined for the crude oil and certain of its fractions along with the specific gravity and range of boiling point, may be of value in indicating the locality from which the petroleum is obtained.

They also state that on the average for each rise in temperature of 1°C.

[4] Data from Rittman and Egloff, Utz, and Bell, here given, were obtained through Geological Research Service, 60 East 96th Street, New York City.

[5] Rittman and Egloff, *Jour. Ind. Eng. Chem.*, Vol. 7 (1915), p. 578.

[6] W. A. Hamor and F. W. Padgett, *The Technical Examination of Crude Petroleum Petroleum Products, and Natural Gas*, McGraw-Hill Book Company, New York (1920), p. 11.

the index of refraction decreases 0.0004. Francis and Bennett[7] (1921) give data on refractive indices and Baumé gravity of a number of petroleum oils. The relation is variable for individual samples but shows a general increase in refractive index with decreasing Baumé values.

Utz[8] (1921) made a rather extensive investigation of the refractive indices of light crudes and their distillation fractions and the relation of refractive index to specific gravity. Some of the data given in his paper are here listed (A.P.I. gravities have been inserted by the writer).

TABLE I

DATA ON FRACTIONS OF CRUDES FROM VARIOUS LOCALITIES
(AFTER ENGLER)

Degrees Centigrade	*Tegernsee (Bavaria)* *Sp. G.*	*Degrees A.P.I.*	*R.I.*	*Pechelbronn (Alsace)* *Sp. G.*	*Degrees A.P.I.*	*R.I.*
140–160	0.7465	58.1	1.427	0.7750	51.1	1.421
190–210	0.7840	49.0	1.437	0.7900	47.6	1.440
240–260	0.8130	42.6	1.451	0.8155	42.0	1.454
290–310	0.8370	37.6	1.465	0.8320	38.6	1.462
	Oelheim (Hanover)			*Pennsylvania*		
140–160	0.7830	49.2	1.435	0.7550	55.9	1.422
190–210	0.8155	42.0	1.450	0.7860	48.5	1.439
240–260	0.8420	36.5	1.468	0.8120	42.8	1.454
290–310	0.8620	32.6	1.485	0.8325	38.5	1.463
	Baku					
140–160	0.7820	49.4	1.436			
190–210	0.8195	41.2	1.454			
240–260	0.8445	36.0	1.467			
290–310	0.8645	32.2	1.475			

TABLE II

REFRACTIVE INDICES OF ILLUMINATING OILS AND FRACTIONS
THEREOF FROM VARIOUS LOCALITIES

Crude Degrees	*Russian*	*Rumanian(1)*	*Rumanian(2)*	*Austrian*	*Gallician*	*American*
	1.4567	1.4573	1.4069	1.4528	1.4545	1.4490
−150	1.4351	1.4345	1.4355	1.4332	1.4330	1.4238
150–270	1.4591	1.4597	1.4606	1.4540	1.4583	1.4496
+270	1.4814	1.4858	1.4872	1.4737	1.4823	1.4692

TABLE III

RELATION BETWEEN SOLIDIFYING POINT AND REFRACTIVE INDEX
OF VARIOUS PARAFFINES

Solidifying Temperature Degrees	*Refractive Index*
50.5	1.4368
51.0	1.4370
51.5	1.4371
52.0	1.4372
52.5	1.4373
53.0	1.4374
53.5	1.4375
54.0	1.4377

[7] Francis and Bennett, *Petroleum Mag.*, Vol. 11 (May, 1921), pp. 134–35.

[8] Utz, "Die Refraktometrische Untersuchung von Erdöl und Erdölprodukten," *Petroleum Zeitschrift*, Vol. 17 (1921), pp. 1293–99.

Gruse[9] (1928) discusses the refractive index of petroleum as follows.

The refractive index of petroleum fractions varies with the type of the prevailing hydrocarbons present. Paraffins have, in general, a lower refractive index (for the same molecular weight) than naphthenes, and naphthenes a lower value than aromatics. The work on refractometric examination of petroleum oils has been reviewed by Utz. It is noted that the refractive index rises with the boiling point of the fractions of a crude oil, and with the melting point of the solid constituents (waxes). . . . The refractive index cannot well be used in identifying crude oils because of the mixed nature of petroleum. Under special conditions it may be employed for estimating the proportion of different hydrocarbons in a closely cut fraction.

Bell[10] (1930) points out that the index of refraction of petroleum and of the fractions distilled from it varies with the specific gravity. The heavier the oil, the higher the index; as the boiling point and the specific gravity rise, so does the index of refraction. Table IV, quoted by Bell and attributed to Engler and Hofer, shows a linear relationship between specific gravities and refractive indices of Pennsylvania and Russian crudes (A.P.I. gravities inserted by the writer).

TABLE IV

SPECIFIC GRAVITIES AND REFRACTIVE INDICES OF PENNSYLVANIAN AND RUSSIAN CRUDES

Pennsylvanian Crudes			*Russian Crudes*		
Sp. G.	*Degrees A.P.I.*	*R.I.*	*Sp. G.*	*Degrees A.P.I.*	*R.I.*
0.7531	56.4	1.4247	0.7780	50.4	1.4377
0.7549	55.9	1.4263	0.7855	48.8	1.4405
0.7580	55.2	1.4275	0.8047	44.2	1.4471
0.7624	54.3	1.4330	0.8165	41.8	1.4559

Bell also states that Predescu found that the index of refraction of dark non-paraffinic, Rumanian crude (sp. g. at 15°C. = 0.8671 = 31.7°A.P.I.) was 1.487 at 15°C. Fractions of 10° difference in boiling point were distilled from this crude and the index of refraction was found to increase from 1.384 to 1.526.

The relation of refractive index to the specific gravity of California oils was recently investigated by D. R. Knowlton.[11] Professor F. G. Tickell of Stanford University called the writer's attention to this interesting piece of work. Knowlton determined the refractive index of about 30 California oils ranging from 14° to 34°A.P.I. gravity. A general relation between specific gravity and refractive index was evident, although individual samples were quite variable.

In Table V is shown the relation between specific gravity, A.P.I.

[9] W. A. Gruse, *Petroleum and Its Products*, McGraw-Hill Book Company, New York (1928), pp. 87–88.

[10] H. S. Bell, *American Petroleum Refining*, 2nd Edition, D. Van Nostrand Co., New York (1930), p. 48 *et seq.*

[11] D. R. Knowlton, unpublished thesis, Stanford University.

gravity, refractive index, and boiling point for the liquid members of the homologous series of aliphatic hydrocarbons which are important constituents of the paraffine-base oils.[12] The increase of refractive index with specific gravity and boiling point is very regular in this series. A similar relation appears to exist in the naphthene hydrocarbons and to some extent in the aromatic hydrocarbons which have been identified in petroleum oils.

TABLE V

	Sp. G.	*Degrees A.P.I.*	*R.I.*	*B.P. Degrees C.*
Pentane	0.631	92.7	1.357	36.2
Hexane	.660	82.9	1.375	69.0
Heptane	.684	75.4	1.386	98.4
Octane	.704	69.5	1.397	125.8
Nonane	.718	65.6	1.406	150.7
Decane	.730	62.3	1.412	174.0

REFRACTIVE INDEX OF VENEZUELAN PETROLEUM OILS

The refractive indices, specific gravities, and A.P.I. gravities of a number of Venezuelan oils are listed in Table VI. The relationships between refractive index and specific gravity, and between refractive index and A.P.I. gravity are brought out graphically for these oils on Figures 2 and 3. In both cases the relation is approximately linear. There is very little difference between the two, but the refractive index-specific gravity curve is more fundamental than that based on the more artificial A.P.I. scale. For practical purposes, however, the A.P.I. gravity curve is probably the more useful, since in the western hemisphere oil gravities are generally expressed in A.P.I. degrees.

TABLE VI

RELATION OF REFRACTIVE INDEX TO SPECIFIC GRAVITY AND A.P.I. GRAVITY FOR SOME VENEZUELAN CRUDES

	Sp. G. at 60°F.	*A.P.I. at 60°F.*	*R.I. at 30°C.*
1	.763	54.0	1.416
2	.767	53.0	1.426
3	.780	50.0	1.440
4	.793	47.0	1.462
5	.844	36.2	1.491
6	.876	30.4	1.488
7	.886	28.2	1.502
8	.893	27.0	1.511
9	.893	27.0	1.498
10	.907	24.5	1.508
11	.912	23.7	1.505
12	.946	18.0	1.535
13	.952	17.2	1.545
14	.953	16.9	1.547
15	.963	15.4	1.534
16	.966	15.0	1.544
17	.978	13.2	1.564
18	>1.000	<10.0	1.571
19	>1.000	<10.0	1.572

[12] Data from *Handbook of Chemistry and Physics*, 21st Ed., Chemical Rubber Publishing Co., Cleveland, Ohio (1936).

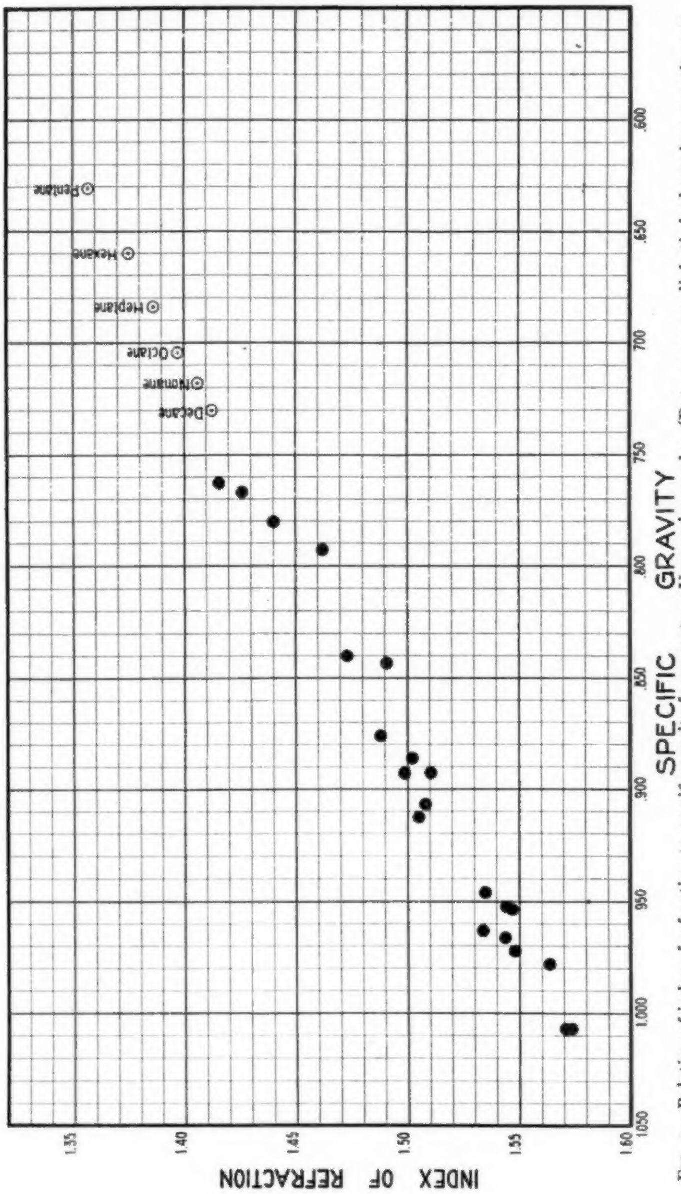

FIG. 2.—Relation of index of refraction to specific gravity for seventeen Venezuelan crudes. (Data on some aliphatic hydrocarbon constituents of light oils shown in upper right-hand corner.)

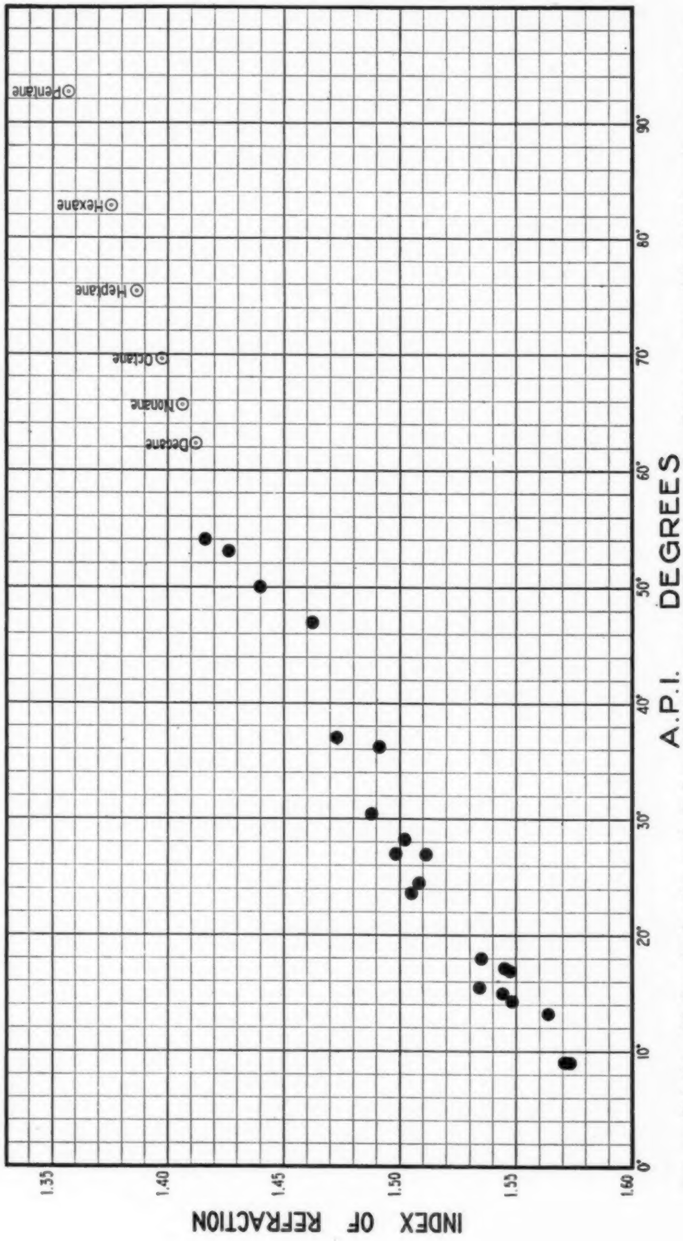

FIG. 3.—Relation of index of refraction to A. P. I. gravity for seventeen Venezuelan crudes. (Data on some aliphatic hydrocarbon constituents of light oils shown in upper right-hand corner.)

Too few data are at present available on the Venezuelan oils to do more than outline relationships in a rough way. However, the general increase of refractive index with increasing specific gravity (decreasing A.P.I. gravity) is clearly demonstrated. The graphs show a number of irregularities and some even wider variations may be found as observations become more complete. However, residuals to an average curve are considerably lower than in the case of Knowlton's[13] California data. Moreover, the data are from widely separated parts of the country and it is probable that for any one area containing a single major source of oil the relation between refractive index and gravity would be found to be much closer.

Data for members of the aliphatic hydrocarbon series given in Table V are shown by open circles in the upper right-hand portions of Figures 2 and 3. It is evident that for this series the linear relation is nearly perfect. The close continuity of data on these important constituents of light oils with data on the Venezuelan crudes is striking.

Such discrepancies as exist between refractive index and gravity readings in no way indicate that refractive index is a less accurate criterion of the commercial value of an oil than is specific gravity. On the contrary, there is some good evidence that the refractive power of an oil is a more fundamental character than specific gravity as usually measured. Thus in the case of two Venezuelan crudes it was found that oil from well No. 1 with a hydrometer reading of 13° A.P.I. had the same refractive index as oil from well No. 2 with a hydrometer reading of 17.2°A.P.I. However, centrifuge tests subsequently showed a large proportion of water and emulsion in the oil from well No. 1, which was undoubtedly responsible for the apparent difference in gravity of essentially identical oils. Similarly, errors in gravity due to the presence of other suspended matter in oil are largely eliminated by the refractometer method.

In light oils, rapid changes take place in refractive index due to evaporation of the more volatile constituents. Thus a light Venezuelan oil increased in refractive index from 1.424 to 1.455 after standing for 24 hours exposed to the air. The same change in refractive index occurred after heating for only a few minutes on a hot plate. Similarly, a medium-gravity oil changed from a refractive index of 1.502 to 1.516 when left exposed to evaporation in a shallow cup for 24 hours. It may be assumed that these changes in refractive index are also approximately paralleled by changes in gravity.

Due to the complex composition of petroleum, it is probable that oils of identical specific gravity but derived from different regions or

[13] D. R. Knowlton, *op. cit.*

different sources in the same region may show a considerable degree of variation in refractive index. A chart of the relation between refractive index and specific gravity for oils of one formation or of one region will not apply exactly to those of another formation or another region, although the general relation holds. However, a similar situation exists with respect to specific gravity. The commercial quality of all 20°-gravity oils is by no means the same. Moreover, with an adequate geological background as well as adequate data on oils of known quality, this variability in relation of refractive index to specific gravity may in itself be of value in the identification of the source of an unknown oil.

The chief value of refractive-index investigations is in connection with the evaluation of oil sands in which the character of the contained oil is not known. In order to do this successfully, however, it is necessary to build up a background of data on known oils for which the relation of refractive index to other qualities has been determined. Therefore, all available local data should be secured before attempts are made to interpret the refractive indices of unknowns in any area.

EVALUATION OF OIL SANDS BY REFRACTIVE-INDEX METHOD

The principal application of the relation between refractive index and commercial quality of petroleum is found in the evaluation of oil sands encountered during drilling. The importance of knowing the quality of oil in a sand at the time it is cored is obvious. However, it is frequently difficult to make a reliable estimate from mere inspection of the core sample.[14] Here the refractometer provides a rapid and convenient method of determining the quality of the oil in a sand with the paramount advantage that only a drop or two of oil is necessary for an accurate determination.

In many richly saturated sands it is possible to find enough free oil in the core barrel or exuding from the surface of the core to give a satisfactory refractometer reading. In other sands where free oil is not available it is necessary to resort to carbon-tetrachloride extraction. The core sample is broken down in a mortar and an excess of carbon tetrachloride is added. After standing for 10 minutes the solu-

[14] The writer recently tested the ability of individuals to accurately estimate the gravity of oil merely from its appearance in a sand. A number of 20-cc. samples of clean medium-grained sand were prepared. Ten cc. of 10°A.P.I.-gravity oil were added to one, 20 cc. to another, 40 cc. to a third, 60 cc. to a fourth, and 100 cc. to a fifth. The sand and oil were identical in quality in all cases, the only difference being in their relative proportions. A number of geologists were asked to line up these "oil sands" in order with respect to gravity and to estimate the A.P.I. gravity of the oil in each sand. Almost invariably the samples were ranked in order of the *quantity* of oil present and the gravity range of the series was usually estimated at from 10° to about 30° although the oil in all samples was actually 10°A.P.I.

tion of oil in tetrachloride is filtered into an evaporating dish and the filtrate is evaporated on a hot plate until only a small quantity of liquid remains. The final evaporation is then allowed to proceed at room temperature until all or almost all of the carbon tetrachloride is gone. A thin film of the oily residue is smeared on the surface of the fixed prism of the refractometer, and, after letting it stand for a few more minutes to allow the last traces of carbon tetrachloride to disappear, the refractive index is read.[15] In very heavy oils a few drops of carbon tetrachloride are placed directly on the oil smear and worked around on the prism surface with a wooden swab in order to form a smooth, even film of oil.

The use of carbon tetrachloride with medium or heavy oils introduces little or no error as long as sufficient time is allowed for its evaporation. The boiling point of carbon tetrachloride at normal pressure is 76°C., considerably lower than that of most of the constituents of these oils. In very light oils, however, some of the more volatile fractions of the oil are inevitably lost during evaporation of the carbon tetrachloride so that the refractive-index reading for the extract is somewhat higher than for the free oil.

Carbon tetrachloride extracts have for years been used for the determination of the specific gravity of oil in oil sands by regulating an alcohol-water mixture to the point where a drop of the extract barely sinks in the mixture and then determining the gravity of the mixture with an ordinary hydrometer. The method is fairly successful but, as compared with the refractive-index method, has the disadvantage of a more difficult technique and of several additional sources of error resulting from the effects of surface tension and included air bubbles and from the retention of small amounts of carbon tetrachloride or other impurities in the oil.

The refractive-index method of evaluating the quality of oil in sands has not yet been widely applied and many refinements in the procedure discussed here are to be expected with further experience. However, the writer is already convinced of the usefulness of the refractometer as a tool for the petroleum geologist and the petroleum engineer. It provides a rapid and fairly reliable estimate of oil quality which may prevent the passing up of valuable sands or the wasting of time in the testing of relatively worthless sands. It also provides a valuable criterion for the identification of oils of similar provenance and for the correlation of oil-bearing horizons between different wells.

[15] It is useful to know that the refractive index of carbon tetrachloride is 1.4630 (15°C.)

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 11 (NOVEMBER, 1937), PP. 1477-1485, 2 FIGS.

COLORIMETRIC METHOD OF DETERMINING PERCENTAGE OF OIL IN CORES[1]

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ABSTRACT

If uniform quantities of oil sand and solvent be used in sample bottles when testing cores, and the colors of the solvent be compared with other samples of known concentration, it becomes possible better to evaluate the productive qualities of the sand. This method permits a more accurate judgment than is possible by visual examination of the cores and thereby assists in deciding which sands should be tested in a zone where saturation varies.

The water troubles that follow the development of an oil field are problems for the petroleum engineer. But sometimes the geologist is asked to render an opinion. In examining cores from an oil zone he is confronted with the difficulty of distinguishing saturated oil sands from those containing oil with a slight amount of water but sufficient to cause a poor completion.

This paper has to do with a simple mechanical method of recognizing partly flooded sands as such and in ascertaining their relative abilities to give up oil. The tests have been made from cores of wells drilled in Santa Fe Springs, which is approximately 12 years old, and Olinda, a field that is 37 years old.

The method is particularly applicable in both places. At Olinda about 2,000 feet of sand contains oil in varying amounts from complete saturation to merely a slight stain. Two different gravities are encountered which color the sands by different amounts.

At Santa Fe Springs a single zone such as the Meyer sand will have a thickness of 500 feet and contain as many as 12 streaks of shale between which may exist variations from saturated oil sand to gray sand. This is only one of nine zones capable of production between 2,200 and 8,000 feet.

Several different gravities are encountered with varying abilities to stain the sands. Oil from the Meyer zone with 34.4° gravity and from Nordstrom zone with 33.3° gravity affect the cores almost alike, but the Bell zone oil, with a gravity of 32.3°, gives a much deeper stain. The eye can not do justice to these variables and properly evaluate the cores. To obtain the greatest production it is necessary

[1] Manuscript received, August 23, 1937.

[2] Box H.

to draw sharp lines between the sands that are worth including and those which are not.

In a partly exhausted zone such as the Meyer sand, drainage throughout a long period has had a selective action on the varying porosities and textures. Coarse-grained sands have become depleted while the fine-grained streaks are still saturated. This is accounted for by the rapid drainage through the coarse sands and very slow movement of oil in the beds of fine grain due to high frictional resistance and greater capillarity.

Encroaching edge water develops into lenses of intermediate water in the coarse sands. It is also true that these lenses will develop faster along well sorted sands which because of greater porosity offer less friction, and particularly so if the grains be well rounded.

If perforations are opposite both the saturated and depleted sands, a smaller yield is obtained than if they are confined to the saturated sands. Within the past year, wells producing from 200 to 300 barrels have been completed in the Meyer zone at Santa Fe Springs with only 60 feet of perforations. The water cut is less than 1 per cent. Other wells in the same zone only one location away with 400 feet of perforations have a gross production testing 70 per cent water and net less than 100 barrels of oil per day. Both wells are producing from the saturated sand, but in the poor completion the depleted sands, also opposite the perforations, are yielding water which obstructs the flow of the oil.

Sometimes even a little water is objectionable. Having greater surface tension than the oil, it tends to dominate the situation because of greater power to travel. It is then quite important to determine which are saturated oil sands and which are partly depleted. A water sand is easily recognized by the absence of oil odor and by the gray color in contrast to the brown or tan color that is normal. But the gradations between oil sands and oil sands that contain a little water, are more difficult to recognize. Changes from a brown to a gray-brown may fail to register, especially where an oil zone gradually alters to a bottom water.

If a mining company were to depend on a visual assay to guide the exploration work, it might easily become bankrupt. It is dealing with a valuable mineral and so the assayer, by quantitative tests, distinguishes the good from the bad. The oil company is also dealing with a valuable mineral but in a less precise manner. The words "oil sand" have been used for saturated oil sands and for water sands containing some oil, which are found to be a detriment to a well. The words should be quantitatively defined when water trouble is anticipated.

The following description concerns a quick method of finding the percentage of oil by volume in oil-sand cores. A uniform amount of the oil sand is introduced into a uniform amount of solvent. The color imparted to the latter by the oil is compared with the colors of five standard bottles containing the same kind of oil in the same kind of solvent in known percentages.

The method is valuable in a partly exhausted zone where it is essential to distinguish between the saturated oil sands and those containing both oil and water. It gives a quantitative comparison of the percentage of oil in the cores after they have reached the surface. This may be quite different from the oil content of the sand before it was cored. The strongest sample found in any Santa Fe Springs core has not exceeded 14 per cent when tested by this method. The porosities of the sands are as much as 30 per cent. It would seem in such circumstances that 16 per cent of the oil has been lost.

As the dissolved gas in the oil core expands due to diminishing pressure during the upward journey, the bubbles carry away part of the oil. Since this factor causes only a gradually increasing loss with depth, because of more dissolved gas, differences in oil content of a given zone can still be interpreted as being due to the original condition of the cores.

Both of the other factors may cause irregularities that leave some doubt about the original saturation of the oil sand. If the driller takes only 20 minutes to drill through 20 feet of loosely consolidated sand or as much as 8 hours to drill 3 feet of hard sand, it makes a big difference in the length of time a given core is subjected to washing by the circulating mud. The permeability of the sand accentuates or minimizes this factor. A stream of mud is flowing parallel with the surface of the core with equal pressure on all sides. It may flush the sand but usually there is little tendency for it to circulate through the core and remove the oil, although it does remove some on the outermost edge. If the sand is coarse, the mud circulation will penetrate more deeply.

The time elapsed before the core is examined also makes a difference in the results obtained. Immediately after being removed from the well it has the maximum saturation in the center; hence the outside and both ends are peeled off in order to obtain the richest sand which has not been in direct contact with circulating mud.

But if a day or two has elapsed before the core can be examined, the richest part is then the outside part. The oil has moved toward the surface, evaporated and left a heavy residue in higher concentration on the outside. Since this is what gives the oil its color and was

distributed equally through the sand originally and since this coloring matter is the basis of the quantitative analysis, it is necessary to obtain an average by crushing and mixing a section of the core which includes both the outside and the inside.

METHOD OF TAKING AND TESTING SAMPLES

A measuring rack was first made by joining two pieces of wood in the shape of a piece of angle iron. As illustrated by Figure 1, holes were bored into the horizontal member to accommodate several 4-dram cylindrical vials. Each of these was filled by means of a burette with 7 cubic centimeters of cleaning solvent. A horizontal line was

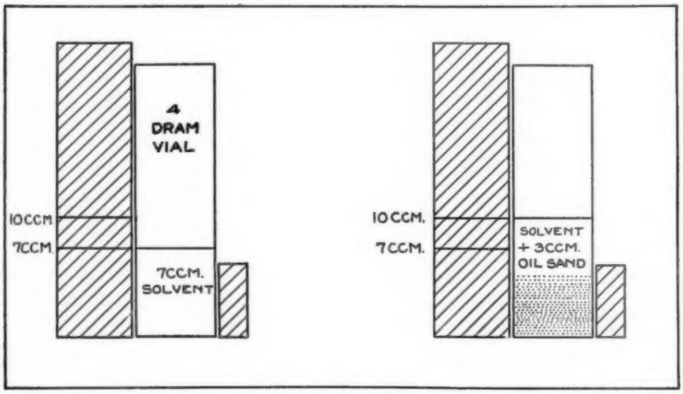

Fig. 1.—Diagram showing measuring rack for colorimetric testing of core samples.

then drawn on the vertical member of the rack, coinciding with the average tops of the menisci. Another line for 10 cubic centimeters was also drawn.

Several 4-dram vials are placed in the rack and filled with cleaning solvent up to the 7 cubic-centimeter mark. Crushed oil sand from the center of a core is added by means of a small funnel until the fluid level matches the 10 cubic-centimeter mark. Samples like this are taken from every tray or from alternate trays of the cored oil sand. They are compared by transmitted light with five standard bottles containing known percentages of oil from the same zone from which the core came.

The latter were prepared as follows. Meyer zone oil from the General Petroleum Corporation's Sante Fe 1 A was whirled in a

centrifuge until it tested 34.4°A.P.I. gravity with less than 0.1 per cent of mud and bottom settlings. Five drops of this oil were placed in a 4-dram vial. Cleaning solvent was added until the top of the meniscus of the fluid matched the 10 cubic-centimeter mark. Four other standard samples were similarly prepared except that they contained 10, 15, 20, and 25 drops of clean Meyer zone oil. It was found that there were 44 drops of this oil to the cubic centimeter at 65°F. The same burette should be used for measuring the drops into the sample bottle and for obtaining the number of drops in a cubic centimeter, because drops vary with the size of the orifice on which they form. The volume concentrations in the five bottles are shown in Table I.

TABLE I

Number of Drops	*Percentage of Oil by Volume in Standard Bottles*
5	1.13
10	2.27
15	3.41
20	4.54
25	5.68

The colors by transmitted light range from pale yellow to a very deep red. These are the standards for comparison to determine the percentage by volume of oil sands from the Meyer zone.

For example, 3 cubic centimeters of oil sand from a core gives to the 7 cubic centimeters of cleaning solvent in which it is immersed, a color that matches by transmitted light the standard bottle containing 20 drops of Meyer zone oil. The latter is 4.54 per cent oil by volume. This must also be true of the 7 cubic centimeters of cleaning solvent in the sample bottle. But the oil in the 7 cubic centimeters of cleaning solvent came originally from 3 cubic centimeters of sand which by inverse ratio of volumes contained $7/3 \times 4.54$ per cent or 10.5 per cent of oil.

Although only five standard bottles are actually used, the following table gives percentages ranging from 5 to 25 drops, so that interpolations may be made. The relationship between the concentration by volume of the oil in the sand samples and the standard bottles is shown in Table II for the Meyer zone.

Standard bottles were prepared of Nordstrom zone oil from the General Petroleum Corporation's Santa Fe 152 D at 74°F. with A.P.I. gravity of 33.3° run in a centrifuge. As this also contained 44 drops to the cubic centimeter, Table II is applicable when comparing these bottles with Nordstrom sands.

In testing the Bell zone the same method and quantities were used as previously described for the Meyer zone. The scale of values is

slightly different because at 65°F., the temperature when the samples were prepared, instead of 44 drops of oil, there were 43 drops to the cubic centimeter of the Bell zone oil taken from the General Petroleum Corporation's Santa Fe 44 and whirled in a centrifuge until the cut was less than 0.1 per cent. The A.P.I. gravity was 32.3°.

TABLE II

Standard Bottles		Sample Bottles Matching Standard Bottles in Color
Number of Drops of Oil	*Percentage of Oil by Volume*	*Percentage of Oil by Volume in Oil-Sand Sample*
5	1.14	2.65
6	1.36	3.18
7	1.59	3.71
8	1.82	4.24
9	2.04	4.76
10	2.27	5.29
11	2.50	5.82
12	2.73	6.35
13	2.95	6.88
14	3.18	7.41
15	3.41	7.94
16	3.64	8.47
17	3.86	9.00
18	4.09	9.53
19	4.32	10.06
20	4.54	10.59
25	5.68	13.24

TABLE III

Standard Bottles		Sample Bottles Matching Standard Bottles in Color
Number of Drops of Oil	*Percentage of Oil by Volume*	*Percentage of Oil by Volume in Oil-Sand Sample*
5	1.16	2.70
6	1.39	3.24
7	1.62	3.77
8	1.86	4.33
9	2.09	4.87
10	2.32	5.42
11	2.56	5.96
12	2.79	6.5
13	3.02	7.0
14	3.25	7.57
15	3.48	8.10
16	3.72	8.67
17	3.95	9.20
18	4.19	9.76
19	4.42	10.30
20	4.65	10.83
25	5.81	13.54

The concentrations in the standard bottles would have to be changed with oil of higher or lighter gravity and this is also true of the proportions of oil sand and solvent in order that the samples will transmit light for comparison.

In these tests the factor of porosity has been omitted and so the results do not give the actual percentage of saturation. If a core tests 10 per cent of oil by volume one does not know whether it came from a saturated sand with a porosity of 10 per cent or from a $\frac{1}{3}$ saturated sand with a porosity of 30 per cent. The former might be a successful completion, and the latter, a water well.

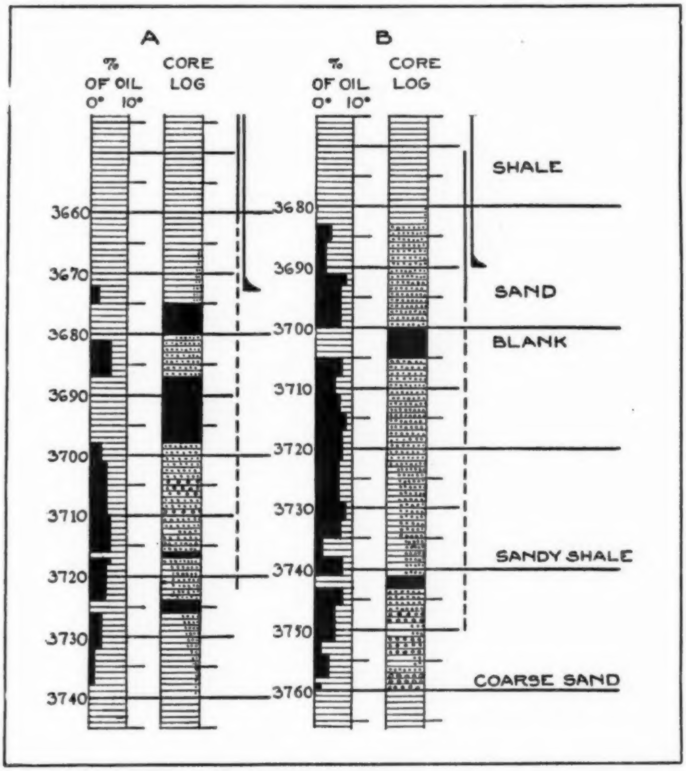

FIG. 2.—Diagram showing percentage of oil in core logs from two wells in the Bell zone at Santa Fe Springs.

But the results of this rapid method do afford a comparison on a percentage basis of the amount of oil in the cored sands and, generally speaking, those showing the highest oil content will also be the most productive.

The results are graphically shown in a column opposite the oil

sands tested and thus indicate at a glance the most desirable points for plugging and perforating in order to exclude partly exhausted sands and include the richer members of a zone. The proof that the method can evaluate the sands is supplied by Figure 2, which represents the core logs of two wells in the Bell zone at Santa Fe Springs, 400 feet apart with no intervening wells. The sand is the same thickness and the samples were compared with the same standards. A 2-column log is used with 1-foot subdivisions. Since the cored interval is logged foot by foot, it should be plotted the same way rather than attempt to crowd the observations into 10-foot subdivisions represented by 0.1 inch, as is commonly done. The column on the right shows the formations, while the one on the left indicates the percentage of oil by volume in the sand, using the full width of the column as 10 per cent. When an oil-sand core is more strongly saturated, part of the space between the two columns is used to show the additional strength. Otherwise this space may be used for the driller's log. Where water is definitely shown by the cores, it is a good plan to emphasize it by a symbol in the left column. Brown is used for oil and blue for water. Some sands will show both.

If the results have a quantitative significance, the well with the smallest area in the saturation column colored to represent oil, should have the smallest production. That has proved to be the fact. The well in which the cores showed lower saturation, even with the advantage of a 3-inch pump and tubing, is able to do only 380 barrels per day, while the well with the greater saturation is producing 530 barrels per day with the handicap of 2½-inch tubing and pump. The areas showing relative quantities of oil in the two wells are in proportion to their productions. The original estimate came within 15 barrels of the actual production.

In one Meyer well, the results were misleading in regard to a 3-foot streak of what appeared to be slightly oil-stained gray sand near the bottom. When completed the well made less than 1 per cent of water.

The sand was actually somewhat gray and did contain water as a core, but it must have been an oil sand before being cored, otherwise the well would have made more water. Flushing by the circulating fluid, in this case, may have removed the oil. Later this core and overlying rich sands were compared for their salt content and there was practically no difference. Had the gray sand been occupied by the strong salt water of this field, some residue would surely have remained, but as an oil sand flushed of its oil by circulating fluid, it would not have shown any salt content greater than other oil sands.

Of the many wells examined this is the only one where any part of the core gave what may be considered a questionable result. The nearest wells to this one were cutting 25–75 per cent water in the same zone and, because of the gray sand streak in the bottom, it was thought that this well would act like its offsets.

Some experiments were tried with different solvents. Ether escapes from the vials because of high vapor pressure and some samples it is desirable to save. Carbon tetrachloride has this same fault to a lesser extent, but it is a poison. Cleaning solvent has low vapor pressure compared with the other two and so the samples may be kept indefinitely and it is also an excellent solvent. It was used in preference to any others. Ether has one advantage. In it water and oil are miscible in all proportions. All samples when freshly taken from the well may have a small per cent of moisture that has worked its way into the core by capillarity from the surrounding mud fluid. A very slight bit of water forms films around small aggregates of sand in which are enclosed minute quantities of oil that never get into solution when carbon tetrachloride or cleaning solvent is used. But with ether these water films are dissolved and all of the oil goes into solution, thus giving a more exact colorimetric test.

With carbon tetrachloride, the tiny aggregates of oil-sand particles surrounded by water films are made more buoyant because the water is lighter than the carbon tetrachloride. If much water is in the sand, it gives the latter a bulky and flocculent appearance. This is true to a smaller extent with cleaning solvent. A flocculent appearance results, but cleaning solvent is lighter than water and so the water-enclosed aggregates remain on the bottom and appear less bulky than with carbon tetrachloride.

It is possible by this rapid method to sample, test and plot the results of 150 feet of cores in a day. The small cost of doing this work, compared with the high cost of obtaining the cores, makes the additional expense negligible, but with such a method in a field where water interfingers with the oil, perforations may be confined to thin streaks of rich oil sand and water sands may be better excluded with greater ultimate recovery.

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VOLUME RELATIONS IN OPEN-SPACE REPLACEMENTS[1]

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ABSTRACT

Metasomatism of the igneous and the metamorphic types takes place volume for volume, as has been proved by Lindgren and others. This concept has not been applied to "open-space" replacement (including hydration), which commonly takes place near the earth's surface under normal temperature and pressure. The writers hold that this concept is also applicable to the latter reactions and present evidence in support of this contention.

INTRODUCTION

Lindgren and others have proved that metasomatism (replacement) of igneous and metamorphic types rarely, if ever, causes any change of volume. This concept, however, has not been applied widely to those chemical reactions which take place in open space. In fact, geological literature has many references to supposed volume changes under these conditions. Examples of such statements are the alteration of anhydrite to gypsum, of olivine to serpentine, of nepheline syenite to bauxite. All these have produced volume changes according to various authorities. Sometimes it is even assumed that the pressure developed during expansion of volume would produce small surficial folds.

The purpose of this article is to examine the evidence on which these statements rest. This study consists of two phases, the first being a brief review of the physical and chemical factors involved in the process and the second a review of the geologic evidence.

CHEMICAL REACTIONS AND VOLUME CHANGES

A chemical reaction ordinarily is accompanied by a change in the volume of the solids involved. For example, the specific gravity of anhydrite is 2.899–2.985 (average 2.941) and that of gypsum is 2.314–2.328 (average 2.321). Therefore in the change of anhydrite to gypsum according to the equation $CaSO_4+2H_2O=CaSO_42H_2O$, the resulting gypsum has a volume 1.6 times as great as that of the original anhydrite. This calculation is based on the assumption that there is

[1] Manuscript received, July 29, 1937.

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no change in the relative porosities of the two minerals, as, for example, in the alteration of a crystal of anhydrite to a crystal of gypsum.

In the change of calcite to dolomite according to the equation $2CaCO_3+MgCl_2=CaMg(CO_3)_2+CaCl_2$, the dolomite occupies approximately 87.5 per cent of the volume of the original calcite. In the reaction

$$\underset{\text{olivine}}{2Mg_2SiO_4}+2H_2O+CO_2=\underset{\text{serpentine}}{H_4Mg_3Si_2O_9}+\underset{\text{magnesite}}{MgCO_3}$$

the serpentine has a volume approximately 27 per cent greater than that of the olivine and the volume of the serpentine plus that of the magnesite is 60 per cent greater. Numerous other examples could be given, all illustrating the fact that the volume of the solids is in general altered in chemical reactions.

An exception to this rule is furnished by the zeolites. The minerals of this group act as water softeners by exchanging their sodium for the calcium of the hard water in such a manner that there is no disruption of the crystal lattices. Thus in this exchange of bases there would be no volume change. This type of reaction, however, is rare among minerals.

CHEMICAL REACTIONS AND VOLUME CHANGES IN NATURE

In nature, closed systems are rare, for the reacting solutions ordinarily are moving. Even solutions in capillary openings have some circulation. Therefore, in nature, though the products of a reaction have different volumes from the original material, these products may be transported by the moving solutions; hence, there may or may not be a volume change at the location of the reaction. A reaction may take place very slowly in nature and the moving solutions may act for months on a single crystal and distribute the new substances far and wide. It might be argued that since the products are insoluble, they are precipitated at once, thus forming a closed system. If the degree of supersaturation is great, spontaneous crystallization may occur, but even in this case there remains dissolved an amount equal to the solubility under the existing conditions and this may be a small or a large fraction of the total amount. Furthermore, if the reaction takes place slowly and involves a large amount of water, the total amount remaining in solution may be a large fraction of the product or at times all of it. In some reactions only part of the resulting material is precipitated locally, and porosity develops.

In many cases the major part of the product is precipitated near the seat of the reaction, but the exact amount can not be computed from data available to the geologist, for he can not determine the pre-

cise concentration, temperature, *et cetera*, of the solution involved in past geologic time. Therefore, the question of volume changes produced by chemical reaction must be answered for each case by the geologic evidence and not from theoretical chemical computations.

Whether the solutions involved were coarse suspensions, colloidal or true solutions, in no way alters these considerations relative to the volume of the original material and the products and the *loci* of deposition of the latter.

MECHANICS OF HYDRATION

It has been clearly established by Lindgren and others that metasomatism is a matter of solution of one material and the precipitation of another. A few geologists, however, apparently consider hydration a different process. Their assumption seems to be that anhydrite simply attaches water to itself in some peculiar physical or chemical manner to form gypsum, and that the anhydrite is not dissolved in the process. This, of course, is erroneous. The anhydrite dissolves and later the gypsum is precipitated. Anhydrite is orthorhombic, gypsum is monoclinic, and the atomic structures of the two minerals are quite distinct. There is no way in which the water molecules could be attached to anhydrite to give the atomic structure of gypsum without completely disrupting the anhydrite. The water of gypsum is exactly what it is called, namely, "water of crystallization."

Two special types of hydration are considered for the sake of completeness, though neither involves water of crystallization. The first type is illustrated by the zeolites, which are well described by Dana[4] as follows.

> The water contained in the zeolites differs from the ordinary water of crystallization of other minerals. When the zeolites are heated, the water is given off readily and continuously and not in certain amounts at definite temperatures as is usually the case. Further, the partially dehydrated mineral can again take up an equal amount of water if exposed to water vapor. The optical characters change gradually on dehydration, but apparently the atomic structure (as shown by X-ray study) remains the same unless the process is carried nearly to completion. Further, the partially dehydrated mineral can absorb other materials in place of the water, such as air, ammonia, alcohol, hydrogen sulphide, iodine, etc. It would appear that the water occupies at least an unimportant position in the atomic structure of the zeolites, possibly being present as adsorbed water held in openings or channels of the structure.

The second type is bentonite. These clays have montmorillonite or beidellite as the dominant mineral and they possess the peculiar property of swelling when in contact with water. The new volume

[4] James Dwight Dana, *Textbook of Mineralogy*, 4th edition, by W. E. Ford, p. 643.

may range up to 15 times that of the dry clay. Outcrops of such clays have wrinkled surfaces due to the expansion. The outer part of the rock swells first while the interior is still dry. The latter part finally absorbs water and expands, producing cracks in the surface layers which meanwhile have become dry.

The swelling of bentonite is complex. It appears to involve absorption, adsorption, and chemical reaction.[5] If the bentonite is composed mainly of crystalline material, the swelling is due to crystalline adsorption. If the bentonite is composed chiefly of lyophilic colloids (water-absorbing colloids), the swelling is caused by absorption.

Hydration of the zeolites and bentonite varieties play little part in the types of reactions with which this article is concerned and are mentioned here mainly for completeness.

GEOLOGIC EVIDENCE ON VOLUME CHANGES IN CHEMICAL REACTIONS WHICH TAKE PLACE IN OPEN SPACES

A few examples of field occurrence may now be given in which "open-space" conditions are believed to have been present during the process of replacement and in which there appears to have been no change in the volume relations. These are, the formation of bauxite from syenite in the Arkansas occurrences, the serpentinization of basaltic lavas, probably subaqueous extrusives, in the serpentine oil fields of Texas, the silicification of wood, and the hydration of anhydrite of the Blaine formation of Oklahoma.

The bauxite deposits of Arkansas are the result of weathering of nepheline syenite and now form a residual mantle over the syenite. The upper ore is characterized by a texture described as oölitic or pisolitic and some larger concretionary forms. These are common forms of weathering products of alumina and iron oxides, in the formation of bauxite and laterites. Below the upper ore is found a zone,

> having the texture of the syenite commonly called sponge ore or granitic ore. This bauxite preserves in varying degree the original granitic texture of the syenite.[6]

The granitic ore grades upward into the oölitic ore and downward into the kaolinized syenite and the latter into unaltered syenite. The granitic texture of the syenite is preserved in the kaolinized syenite and in the granitic type of bauxite. The ores have a high porosity, the average being 38.5 per cent.

[5] C. W. Davis and H. C. Vacher, "Bentonite, Its Properties, Mining, Preparation, and Utilization," *U. S. Bur. Mines Tech. Paper 438*, p. 24.

[6] C. K. Leith and W. J. Mead, *Metamorphic Geology* (1915), p. 36.

In the microscopic examination of the oölitic ore Leith and Mead[6] found,

the ore reveals abundant feldspar forms in the oölite. These feldspar forms usually consist entirely of microcrystalline gibbsite, and are very striking indeed under the microscope, some of them even showing traces of the twinning of the plagioclase feldspar.

In mineral composition,

the pisolitic type of ore is made up largely of the amorphous form, but this type of ore also contains a considerable amount of the crystalline form in the shape of remnants of feldspars which have been completely altered to gibbsite.

Apparently replacement, to form gibbsite after the feldspars, takes place near the surface of the deposits. The formation of gibbsite probably is a stage in the alteration to the oölitic ore. The pseudomorphic nature of this replacement indicates that there has been no increase in volume in the alteration, though a high degree of porosity has developed.

In the so-called "serpentine" oil fields of Texas[7] the serpentine has been traced into the basalt. This lava apparently, in most occurrences, was extruded on the sea floor and converted into a volcanic tuff consisting of boulders and finer pyroclastic material, in late Cretaceous or Austin time. It is possible that some of the material was also extruded upon the land. In either case, the material since has been altered into chloritic rock, commonly known as serpentine, in which the original texture generally has been preserved almost exactly.

Tomlinson[7] observed from his microscopic analysis that

the original texture is sufficiently preserved to enable one to recast the original rock with a fair degree of certainty. These sections show outlines of phenocrysts of augite set in a base of brownish glass. Breccias show large angular fragments of the metabasalt with concave sides as though broken from a cellular rock.

Larson, who also made an examination of the serpentine from slides, writes,

the rock was unquestionably porphyritic . . . has scattered crystals . . . in a fine textured or glassy groundmass . . . bodies resembling spherulites, as if the original rock was in part glassy.

Udden and Bybee, in their early examination of the serpentine,

found a few hexagonal outlines of the original nepheline and practically all showed traces of original crystal boundaries.

[7] J. A. Udden and H. P. Bybee, "The Thrall Oil Field," *Univ. Texas Bull. 66* (1916).

It is interesting to note that these observers state that in the alteration of olivine to serpentine,

cracks form with the increase in volume accompanying the serpentinization.

This conforms to the prevailing concept in the volume relations. It is obvious that there is a confusion between expansion and porosity.

All who have examined the serpentine seemingly agree that the alteration products in many places have preserved accurately the form of the original mineral and the shape of boulders and fragments of rock. In the Lytton Springs area, according to Collingwood and Rettger[8] it has been possible to determine that the original igneous rock is partly extrusive and partly intrusive. These pseudomorphs denote a lack of volume change.

The areas of the serpentine have attracted considerable attention as oil-producing areas in which the serpentine is the reservoir rock. These include Thrall, Chapman, Yoast, Lytton Springs, and others which by 1932[9] had produced a total of 13 million barrels of oil, some of the initial production ranging up to 5,000 barrels. In other areas, while drilling for oil, water also has been encountered in considerable quantities. From these occurrences of oil and water in the serpentine, it is obvious that it is a comparatively porous rock. Porosities have been found ranging from 21.7 to 35.6 per cent. This is comparable with the pore space of a good reservoir sandstone. The serpentine varies in thickness from inches at the margin to 500 feet or more, and in the Chapman area one well penetrated 954 feet of it.[10] It is thought that the lower part of the serpentine in this case represents the vent through which the extrusion took place. With one possible exception, doming of the overlying rock has not been found. If expansion of the volume has taken place during serpentinization, it would seem likely that the original forms of minerals and the rocks would have become distorted and the porosity, or interstitial space, reduced approximately in proportion to the supposed volume increase. This would be particularly true in the deeper part of the serpentine, which would carry considerable overburden. Moreover, doming of the overlying rock should be expected unless it should be postulated that the serpentinization took place before the subaqueous flow was entirely covered.

[8] D. M. Collingwood and R. E. Rettger, "The Lytton Springs Oil Field, Caldwell County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 10 (October, 1926), pp. 953–75.

[9] E. H. Sellards, "Oil Fields in Igneous Rocks in Coastal Plain of Texas," *ibid.*, Vol. 16, No. 8 (August, 1932), pp. 741–68.

[10] John T. Lonsdale, *Univ. Texas Bull. 2744* (1927).

Without evidence for expansion *en masse* during the process of serpentinization, with porosity comparable with that of a good porous sandstone and the accurate preservation of the form of the minerals and rocks, it does not seem likely that the alteration has been accompanied by an increase in volume of the serpentine over that of the original mass of the submarine flows. Here also the formation of serpentine must have taken place in open space, for considerable interstitial space existed between the fragments of the subaqueous flow.

Further, may be mentioned other pseudomorphs formed at or near the surface which are familiar to all geologists. A few of these are limonite after pyrite cubes, pyritized crinoid stems, quartz in rhombohedrons after calcite. These and many others show no distortion of the original form. Obviously replacement takes place in open space as well as in solid rock, provided that a transporting fluid is present in which solution of the host and deposition of the guest may take place.

In the replacement of wood by silica, the original form and cellular structure of the wood have been accurately preserved. The replacement must have been near the earth's surface where open space is common both on the surface of the wood and throughout its cellular structure. Everyone is familiar with the completeness of the reproduction of the surface features of the wood as well as the cellular structure. It is interesting to note that in this case replacement is rapid, for it must have taken place before the cellular structure and form of the wood were destroyed, probably within a very few years. Perhaps replacement in other cases may also be rapid. This point is worthy of further investigation.

That expansion in volume takes place on hydration of anhydrite to gypsum is an old and firmly fixed conception in geologic literature which has held sway for more than a century. Muir[11] investigated the Blaine gypsum of Oklahoma. He observed in thin sections that fragments of anhydrite separated by gypsum had optical continuity. This indicates that the separate anhydrite pieces were once part of the same crystal and that the replacement by gypsum had caused no displacement. In the field no evidence of distortion was found where tongues of gypsum extended into the anhydrite, the original thickness of the bed being maintained. The crenulations often quoted as evidence of distortion are not noticed in the Blaine gypsum. The crenulations in other areas are probably drag-folds in an incompetent rock where there has been regional disturbance. These types of

[11] J. Lawrence Muir, "Anhydrite-Gypsum Problem of Blaine Formation, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1297–1312.

minor folds or crenulations are commonly found in disturbed, incompetent, homogeneous rock.

Commenting on Muir's findings, H. S. Griley[12] believes that the small ridges common in the gypsum area of western Oklahoma are due to expansion in the formation of gypsum from anhydrite. The folds described by Griley are 15–20 feet across and 5–8 feet in height. Some are open anticlines, only the upper few feet of sediments being disturbed. Griley's statement, "Folding can be seen both in ledges of gypsum having the usual basal dolomite and in the dolomite where there is a local absence of gypsum," seems adequately to disprove that the folds are due to expansion in the formation of gypsum. Surficial folds of a similar nature have been reported by Campbell[13] in sandstone in Arkansas and by W. Armstrong Price in limestone.[14] In these the folding must be due to causes other than that of hydration.

In conclusion, the writers are convinced that replacement takes place in open space as well as in solid rock without change in volume.

[12] J. Lawrence Muir, *op. cit.*, pp. 1310–11.

[13] *Jour. Geology*, Vol. 14, pp. 718–21.

[14] W. Armstrong Price, "Caliche and Pseudo-Anticlines," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 6 (September, 1925), pp. 1009–17.

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DISCUSSION

GEOLOGIC SIGNIFICANCE OF A GEOTHERMAL GRADIENT CURVE

The interesting and valuable article in the September *Bulletin* (p. 1193) by Walter B. Lang, giving his careful study of the Getty-Dooley well near Carlsbad, New Mexico, suggests to my mind a possibility, in addition to those which he mentions.

I would not of course deny the importance of varying conductivity and diffusivity of rocks, and I agree that other factors which he considers of minor importance, are so.

But there is one factor which he does not mention, which Fisher, Ingersoll, Vivian, and Hotchkiss accept as important in the gradient of the Michigan copper mines, which I refer to in my paper on "Rating the Geological Clock"[1] and in other papers therein cited.

That factor is long-term changes in the surface temperature—in particular, warming up since the last ice age.

From 4,000 feet, or even 3,500 feet, the rate of increase is quite regular. At 4,000 feet the temperature was 91.7°F.; at 6,000 it was 111.8°F.; that is, in 2,000 feet there was an increase of 20.1°, about 1 degree to 100 feet.

This is approximately the gradient at the bottom of the copper mines which Fisher, Ingersoll, and Vivian give as 1° in 103.1 feet. The same gradient continued back to the surface would give, in Calumet, which is in the glaciated region, a temperature near 32°F., about that of melting ice.

The temperature at the bottom of the Getty-Dooley well would be near 52°F.

Is that not a reasonable temperature to be the surface temperature at Carlsbad, New Mexico, during the ice age?

I would suggest, then, that just as has been found for Michigan, we have signs of heat waves since the ice age which have not reached the bottom of the well.

The crest of one wave seems to be about 3,000 feet down and the other only about 200 feet. Was it exceptionally hot 30 years ago?

In figuring the behavior of such waves, one must have the diffusivity as well as the conductivity. And as the specific heat of water is high, the diffusivity is the conductivity divided by the specific heat-per-unit volume. Thus a rock with water may not be extremely conductive or diffusive, if the pores are so fine that there is no convection.

ALFRED C. LANE

CAMBRIDGE, MASSACHUSETTS
September 17, 1937

The question that Alfred C. Lane has raised concerning the possible effect upon the geothermal gradient of the Getty-Dooley well of a change in the climate of the Pecos Valley following the last glacial stage was not mentioned in my analysis because of the difficulty of recognizing the influence this factor may exercise in modifying the character of the curve. Without doubt the

[1] Report of XVI International Geological Congress, Washington (1933), p. 155.

mean annual temperature of the Pecos Valley area has risen since the close of the Pleistocene period, but at what rate and to what amount is not known with certainty. A rise in the mean annual temperature will permit an upward swing of the upper part of the geothermal curve which, if it were previously a straight line, would then become a curve convex towards the depth axis. This is the same type of curve as is produced where rocks of low conductivity are overlain by rocks of higher conductivity. Therefore, if both factors are present, the part attributable to each is inseparable from the whole unless a precise measure of either one or both effects is known.

Let us assume, as suggested by Lane, that the change in gradient at about 3,500 feet in the Getty-Dooley well is due to the rise in the mean annual temperature at the close of glaciation, a change that in the Pecos Valley was undoubtedly very gradual and probably variable. If so pronounced a change in the curve at this point is assignable to this climatic variation and not to differences in rock conductivity, to what, then, is the more pronounced change in gradient at 1,500 feet due? Certainly there is no known climatic variation in post-glacial time of sufficient intensity to satisfy this result. As analysis seems to suggest that this deviation in the trend of the curve is the result of differences in rock conductivity, the writer is inclined to believe that the flexure at 3,500 feet is due to a similar cause.

The first 500 feet below the surface may be termed the zone of anomalies, for more inexplicable measurements of temperature have been made in this zone than in any other portion of measured geothermal gradients. This status is probably due both to the number of complex disturbing natural influences that are active near the surface and to the spurious readings caused by inaccuracies in manipulation. Thus explanations for problems arising in this zone are usually less satisfying than elsewhere.

The adjustment at 200 feet can not be attributed to any unusual temperature change about 30 years ago. At Roswell, New Mexico, where accurate temperature records have been kept since 1895 which may suffice to cover for this purpose the Carlsbad area, the range for mean annual temperature for this period of 42 years has been less than 5°F. The lowest mean annual temperature of 56.9°F. was recorded in 1912 and the highest, 61.5°F., in 1896.

Now for the purpose of exploration, let it be assumed that 30 years ago a sudden increase of 5°F. in the mean annual temperature occurred and subsequently the temperature has remained constant. Calculating V/V_0 for a 1°F. change in temperature for the period of 30 years, the following factors are obtained for each 100 feet of depth below the surface. Multiplying each factor by 5 gives the effect produced by the 5° change.

Depth in feet	V/V_0 *for 1°F.*	*5°F. change*
100	0.38125	1.91
200	0.07992	0.40
300	0.00862	0.04
400	0.00046	0.00
500	0.00000	0.00

Thus it is evident that the effect produced by a 5°F. change in temperature at the surface is negligible at 200 feet and practically immeasurable at 300 feet in 30 years.

As the atmosphere is a blanket which influences the crustal temperatures

of the earth, changes in its temperature are of interest to the study of geothermal gradients in non-glaciated regions, though perhaps less important than in glaciated regions. A large field of glacial ice is the most effective constant temperature surface control known. For this reason broad, flat regions which have been subjected for a long period of time to continental glaciation are in a most favorable position for test and measurement of the effect of extended atmospheric changes which are deviations from a previously established constant. As this type of effect is regional, all measured geothermal gradients within the region should record it. The presence here of straight-line or concave geothermal-gradient curves therefore requires explanation. Their presence indicates that the controlling influence is due to some other cause than an increase in atmospheric temperature, since the retreat of the ice. It therefore appears desirable that the tests in the Michigan copper mines be supported by others more widely spaced in order to eliminate the probability of coincidence and to establish by exploration the validity of this postulation in areas where the effect is likely to show a maximum and to so measure this effect that a correction factor may be applied to goethermal gradients in other regions where it is of less importance.

W. B. LANG

WASHINGTON, D. C.
October 13, 1937

CORRECTION

WATER-INSOLUBLE RESIDUES

In the October *Bulletin*, in the article, "Water-Insoluble Residues in Rock Salt of Louisiana Salt Plugs," by Ralph E. Taylor, page 1293, line 3 from bottom of text, the word "borosilicate" should be *borate*. The paragraph will then read,

Hilgardite.—This is a new hydrous calcium borate with chlorine.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

"Afrika-Heft" (Africa Number). Several authors, Heft ¾, Band 28, of the *Geologische Rundeschau* (1937), Ferdinand Enke Verlag, Stuttgart.

The "Africa Number" of the *Geologische Rundschau* contains 18 articles—in the aggregate nearly 200 pages—devoted to the geology of South Africa, including the former German colonies of East Africa and Southwest Africa. In the first article Professor Hans Cloos gives his impressions as a traveler in Southwest Africa in 1936. The 28 illustrations, mostly from his photographs and drawings, add much to the interest and value of this excellent introduction.

In the second contribution Georg Knetsch of Breslau discusses the diamond placers found near the mouth of the Orange River. The third article, by the same author, gives a review of the geology of Southern Luderitzland, which stretches northward along the coast from the Orange River. Besides other illustrations there are a geologic sketch map and two structure sections. The strata involved, aside from Quaternary and Recent deposits, are supposedly pre-Cambrian. In the fourth article, Professor Cloos gives a brief progress report of the work of Henno Martin and Hermann Korn of Windhock on the nappe structure of the Naukluft Mountains of Southwest Africa. The fifth article, by E. Reuning of Capetown, describes the gold fields of Ondundu, Southwest Africa. The sixth article, by Professor Cloos, is a brief summary, with geologic sketch map, of an article published in the *Transactions of the Geological Society of South Africa* (1934) by P. F. W. Beetz. It deals with the geology of a part of Southwest Angola. Article 7, by Max Richter, deals with the physiography of Griqualand West.

In article 8, Professor Cloos describes the progress of geologic mapping in the Transvaal. Article 9, by E. Ackermann of Leipzig, is devoted to the succession of prospecting methods, particularly in Northern Rhodesia. Among the methods discussed are geologic mapping, aërial mapping, geophysical work, and drilling. In article 10, H. Schneiderhöhn describes the copper deposits of Northern Rhodesia and Katanga.

The three following articles, 11, 12, and 13, are devoted to East Africa. E. Hennig discusses the step faults. He furnishes a tectonic map of part of East Africa and a structure section showing strong angular discordance between "upper Doggar" and the Tendaguru series (Sequanian to Neocomian); C. Gillman discusses the monadnock problem, coming to conclusions, as he says, that differ considerably from those of Bailey Willis but have much in common with those of Krebs; Gerhard Brennich devotes 30 pages to an interesting account of the more recent results of geological investigations in East Africa.

In the next succeeding article (15) Otto Pratje discusses briefly submarine topography and tectonics on the basis of the soundings of the "Meteor" expedition of the years 1925–27. In article 16, the last one that deals with geology, Hans Cloos discusses the problems of the major tectonics of South Africa and illustrates them with some interesting tectonic maps.

The last two articles are devoted to sketches of the lives of two German geologists who have contributed in a notable way to the geology of South Africa: Erich Kaiser, well known for his great work on the diamond deserts of Southwest Africa, and Karl Mauch, an earlier and less known investigator, whose discoveries in South Africa went unrewarded and who died at 38 from an accident while making a living in a cement plant.

The "Africa Number" of the Rundschau is one of which the editors may well be proud. Everyone interested in any aspect of the geology of South Africa will find in it facts and ideas of interest and value. The more general articles, such as those of Cloos (1 and 16) and Brennich (13) will have a particularly wide appeal.

R. D. REED

LOS ANGELES, CALIFORNIA
September 8, 1937

Geologisches Wörterbuch (Geological Dictionary). By CARL CHR. BERINGER. Printed by Ferdinand Enke, publisher, Stuttgart, Germany (1937). 118 pp. Price (bound), $2.62.

Carl Beringer has written a valuable geologic dictionary which contains not only the meaning of terms, but also rather lengthy explanations. He has included in 118 pages practically all the common terms used in geology. In addition many special terms used in petrography, geophysics, podology, and geography are included.

Unfortunately, the definitions and explanations are all in German and may, therefore, not be of very great help to the American reader. Those who are fortunate enough to have a reading knowledge of German will find this book quite indispensable in keeping up to date on the literature of geology.

W. A. VER WIEBE

WICHITA, KANSAS
September, 1937

Das Ozarkland (The Ozarks). By RUDOLF SHOTTENLOHER. 128 pp. 17 illus. Verlag von Walter De Gruyter & Co., Berlin (1937).

This separate is one of a series of five studies by as many authors which are embodied in a larger work entitled *The American Landscape*. The author of the above report resided in this country one year, 1931–1932, most of which time was spent in southwest Missouri in the vicinity of Springfield.

The sub-title to this separate is "A Mountainous Area in the Plains Country of Inner North America." This partly explains the choice of the region for study, namely, that it is a physiographic and structural anomaly in the center of a continent. Furthermore, the author could find no one volume which gives a comprehensive view of the geology, physiography, climate, soil, vegetation, and culture of this province. In addition, most scientific publications dealing with the Ozarks have not only stressed one particular subject, but have been restricted to the arbitrary boundaries of state lines—for obvious reasons. The author is not bound by such restrictions and attempts to weld all these topics into a unified picture of the Ozarks, which has been accomplished in this very readable report.

The book has three major divisions, which are: the Ozarks as a geomorphologic entity, the Ozarks' position with relation to the great plains

region, and the characteristics of the individual physiographic divisions or landscapes. The geology is discussed first because the author feels that all the elements comprising the Ozarks are directly related thereto.

In discussing the geology, the physical make-up of the materials comprising the rocks is described. The position of the pre-Cambrian igneous rocks at the center of the uplift, and the succession of the various shales, sandstones, cherty dolomites, and cherty limestones as one proceeds away from the center are stressed. The attitude and geographic arrangement of the various strata are delineated in the text and by means of cross sections and maps. The alternation of various rock types together with their arrangement and topographic expression brings the author to his main thesis, in that he calls the Ozarks an example of a typical "Schichtstufenland." This term translated literally is layer-step-land, or a terraced terrane in a series of sedimentary rocks. As developed by the author the strata dip outward from a central uplift, the escarpments face toward the uplift and this topographic expression is dependent on an alternation of strata which are relatively resistant and non-resistant to erosion.

The theory of origin of such a Schichtstufenland is intermediate to peneplanation and strip structural planation. The author believes that the present plateaus and "platforms" are the result of the latest uplift followed by a long period of erosion which is still going on. The point stressed is the development of the "platforms" on relatively resistant rock types, such as sandstones, cherty limestones, and cherty dolomites. Although the plateau areas transgress several formations they are all developed on essentially the same rock type.

Whether American geologists agree with this thesis or not, it is significant that the American theory of peneplanation to explain the plateaus of the Ozarks is not being generally accepted by German physiographers and geologists. As most notable of these the author cites W. Penck.

The great surface expression of chertification is a source of amazement to the author, who makes no attempt to explain the phenomenon. He rejects Dake's theory of silicification of old erosion surfaces, because the Ozark region is a non-arid province (the objection is somewhat vague to the reviewer). He also rejects the magmatic theory of Fowler and Lyden, because it is not broad enough to explain the great regional distribution of the chert. He also laments the lack of a good classification of the terms chert and flint.

The vast amount of solution and its effect upon directing drainage is described. The underground drainage and the surface expression of it, dry valleys, are also discussed. Some general remarks are made and the current theories are presented in regard to the origin of the lead and zinc ores.

The remaining chapters are devoted to a study of the hydrography, forestry, climate, agriculture, culture, and economics of the Ozarks. Here again the author keeps tying the various subjects to the geology, which is an example of the new method being used in Europe in describing an area.

Two new geographic names are proposed, one of which is merely suggested and the other of which is adopted by the author. The term "Ozark Shield" is suggested to replace the term "Ozark Dome," because so vast a terrane is better described by the former. The granite outliers in Shannon County, Missouri, he names Rocky Creek Mountains because of their proximity to a stream of that name.

The bibliography is of immense value to anyone making a study of the Ozarks. The author has made an exhaustive survey of the literature and about 400 titles are cited which embrace almost every subject.

JOHN GROHSKOPF

ROLLA, MISSOURI
September 28, 1937

"Structural Behavior of Igneous Rocks." By ROBERT BALK. *Geol. Soc. America Mem.* 5 (July, 1935). 177 pages, 38 figures, 24 plates.

Petroleum geologists who are interested in the interpretation of structure will find much of value in this book, in spite of a title connoting no connection with oil geology. Many types of fractures are common to sedimentary and to igneous rocks; I have wondered for some time whether structural deformation of sedimentary rocks does not involve flowage of unconsolidated rocks and I now wonder whether something of the flow and fracture pattern of the igneous rocks may not be present, perhaps incipiently, in deformed sedimentary rocks. I surmise that most of us petroleum geologists have much to learn about fractures and fracturing and the story that they tell about structure. Balk gives valuable discussion of flow and fracture systems. The book is interesting and simply written; and any petroleum geologist who was brought up on igneous rocks and who still has a lingering fondness for them as I do will be likely to find the book fascinating reading. Not the least valuable part of the book is its extensive list of references.

The book is the result of the request from the Batholith Committee, National Research Council, to summarize the present state of knowledge of the structural behavior of igneous rocks, and to make it available to American geologists. Part I of the book, Description of Primary Structures, covers: (a) primary flow structures; and (b) primary fracture systems. Part II, Structure Patterns in Igneous Rocks, covers: (a) flow structures, (1) in dikes, (2) in massifs, (3) in steep-walled intrusives, (4) in funnel-shaped intrusives; and (b) fracture systems, (1) in dikes, (2) in massifs, (3) in stocks and plugs, (4) in sills and intrusive sheets. Part III, Related Problems, covers: (a) structural data and mechanics of intrusion, and (b) controversial problems. Part IV, Application of Principles, covers suggestions for structural field work on igneous rocks. Part V, Appendix, gives a selected list of references mostly to papers which appeared after the manuscript had been submitted.

DONALD C. BARTON

HOUSTON, TEXAS
September 20, 1937

Petroleum Technology in 1936. By a group of distinguished authorities under the editorship of F. H. GARNER. Published by the Institution of Petroleum Technologists, London (1937). 326 pages, 8 illustrations. Outside dimensions 6.5×9.25 inches. Order from headquarters of the Institution, Aldine House, Bedford Street, London, W.C.2. Price, clothbound, 7/6.

Each of the twenty-five different sections of this book is in the nature of a review of the literature and technologic progress in some particular phase of petroleum technology. Collectively, these reviews span the entire field of petroleum technology. For several years, the Institution of Petroleum Technologists has been featuring reviews of this character. At first, they were

published in a special review issue of the Institution's monthly *Journal*, but so great has been the demand for them, that the plan has been adopted of publishing them separately, in special volumes. The first of these was published a year ago, reviewing petroleum technology progress during the year 1935 and the present volume is the second of what is hoped may become a continuing series. As a record of year-by-year progress, such a publication is of great value to all students of the petroleum industry and to technologists who seek to keep abreast of the development in this rapidly unfolding field of technology.

Many of the topics in the present volume have been treated more fully in the abstract service, which is also a useful feature of the Institution's *Journal*. In a sense, the annual review volume may be regarded as complemental to the abstract service. This systematic and timely abstracting and reviewing of the principal publications dealing with all phases of the petroleum industry is a service not equalled by any agency in the United States at the present time.

Perhaps the most useful feature of the book is the compilation of a selected bibliography for each of the twenty-five sections, each dealing with a different phase of petroleum technology. Though there have doubtless been many important omissions in compiling these bibliographies, a total of upwards of 2,200 titles are listed and reference is separately made to each in the text. The bibliographies on "Chemical and Physical Refining," "Cracking," "Lubricants and Lubrication," "Special Products," "Asphaltic Bitumen and Road Materials," "Chemistry of Petroleum," Motor Benzole," and "Petroleum Literature" seem especially complete.

The section on "Geology of Petroleum," prepared by G. D. Hobson, discusses the trend of theories relating to origin of petroleum, structural conditions affecting oil accumulation, and reviews recent progress in study of the lithologic properties of oil reservoir rocks. Aërial photography, temperature gradients, and petroleum reserves are also among the topics discussed in this section.

S. E. Coomber, in discussing "Regional Geology and Development," reviews progress in exploration for new petroleum reserves in various parts of the world, notably in the United States, in Central and South America, in Australia, England, and various localities in Europe, Africa, and the Near East.

The chapter on "Geophysics" has been contributed by H. Shaw, and offers a general review of progress in field applications of geophysics in various parts of the world, and separate sections are also offered on the several geophysical methods: gravitational, magnetic, seismic, electrical and geothermal.

In the section on "Production," L. V. W. Clark discusses the development of new information on reservoir fluids and conditions, on acid treatment of wells, repressuring and water flooding, flow of gas-oil mixtures through eductor tubes, gas-lift practice, surface pumping units, sucker rods and rod dynamometers, control of water incursion, use of bottom-hole chokes, paraffine problems in oil production, and disposal of oil-field brines.

The section on "Drilling," also written by L. V. W. Clark, discusses power equipment for drilling purposes and reviews progress in pressure drilling, controlled directional drilling, preparation and properties of drilling muds, handling heaving shales, cementing wells, coring, subsurface photographic methods, and hard-facing of drilling bits by electrical methods.

"Transportation and Storage" is discussed by A. C. Hartley. Among topics discussed under this heading, are construction, corrosion and maintenance of pipe lines, pipe-line transport of natural gas, pumping station operation, and construction and maintenance of steel oil-storage tanks.

H. S. Humphreys contributes a short section on "Ocean Transport," reviewing design, construction and operation of "tankers," and recent registry statistics.

A section on "Chemical and Physical Refining" is by G. R. Nixon. In this, there is first a general review of progress in this field, followed by separate discussion of desulphurization of gas and gasoline, chemical and physical processes of refining as applied to the several products of the refinery, treatment of crude to break emulsions and separate salt, treatment of cracked distillates with acids, zinc chloride, phosphorous pentoxide, and other reagents, the Gray cracking process, clay-treating processes, and solvent extraction methods. Regeneration of used lubricating oils and dewaxing of distillates are also reviewed.

The most extensive and thorough-going review in the volume is that on "Cracking," by Gustave Egloff, Emma E. Crandal, and Martha M. Doty. It comprises a general review and separate sections on world status of cracking, economics of cracking, cracking reactions, liquid-vapor phase cracking, vapor phase cracking, selective or multiple-coil cracking, cracking equipment, cracking with oxidation, electrical cracking, cracking other than petroleum oils, cracking and polymerization of hydrocarbon gases, alkylation, cracking by-products, analytical methods as applied to cracked products, and books and reviews on cracking. Appended is a bibliography of 362 references.

Miss Thelma Hoffman contributes a section on "Natural Gas, Natural Gasoline and Liquid Petroleum Gases," in which are reviewed the results of various investigations of natural gas and methods of producing natural gasoline and liquefied petroleum gases.

A section on "Light Distillates, White Spirit and Kerosene" and their utilization in internal combustion engines, by R. J. Evans, discusses oxidation, combustion and detonation, engine testing, anti-detonants, polymer gasoline and high-octane fuel, volatility and storage stability of motor fuels.

L. G. Callingham is the author of a brief section on "Automobile Engines," reviewing particularly the more recent developments in engine design, and R. Stansfield's section on "Diesel Oil, Gas Oil and Heavy Fuel Oils" discusses Diesel fuel oil specifications, chemical and physical properties of Diesel fuel, engine tests, and reference fuels. The section on "Oil Engines," by C. H. Sprake, discusses use of Diesel-powered trucks and the use of oil engines in aviation, rail transport, shipping, and stationary power plants.

J. L. Taylor, in his review of "Lubricants and Lubrication," discusses production and refining of lubricants and their physical and chemical properties. A bibliography of 269 titles is also given.

W. E. J. Broom contributes a section on "Special Products," with particular reference to hydrocarbons and their derivatives, carbon black, paraffine wax, solvents, naphthenic acids and naphthenates, sulphonic acids and sulphonated oils, insulating oils, insecticides and oil sprays, cutting oils, special lubricants, and coke.

The section on "Asphaltic Bitumen and Road Materials," by A. Osborn, offers a general review of production, consumption, import and export of asphaltic bitumen, together with separate discussions of specific topics, such

as manufacture of asphaltic bitumen, cut-back asphalt, physical and chemical properties of asphaltic bitumen, manufacture and properties of asphaltic bitumen emulsions, road surfacing materials, and methods of examination.

F. B. Thole reviews "Analysis and Testing of Petroleum Products," considering, specifically, methods of crude oil analysis, testing of gasoline and gases, sulphur in gasoline, tests applied to kerosene, Diesel fuel, lubricating oils, and greases and asphalt.

In reviewing "The Chemistry of Petroleum," B. C. Allibone discusses the chemical properties of crude oil and natural gas, gasoline, lubricants, paraffine wax, viscosity and heat-conductivity of complex hydrocarbons, preparation and properties of the simpler hydrocarbons, pyrolysis and isomerization, polymerization and condensation, combustion and oxidation, and synthetic products and chemical reactions.

The status of hydrogenation in various countries, technical developments in hydrogenation of coal, tars and heavy oils and vapor-phase hydrogenation are reviewed in a section entitled "Hydrogenation," by R. Holroyd. "Motor Benzole" is reviewed by W. H. Hoffert, discussing production of benzole by coal carbonization, production of aromatic hydrocarbons by pyrolysis of gases and by alkylation processes; benzole recovery from tar, from coal gases and by adsorption processes. Refining of benzole is also reviewed, considering specifically, processes requiring resinification and oxidation, hydrogenation, adsorbents, acid-washing, use of metallic chlorides, removal of sulphur by carbon disulphide, sweetening by removal of mercaptans and other reagents, properties and uses of motor benzole, and methods of analysis.

The subject of "Synthetic Fuels" is reviewed by Angus Macfarlane, discussing the Fischer-Tropsch process, production and purification of synthesis gas, design of reaction vessels, catalytic conversion of gas into oil, and treatment and properties of the products and synthesis of hydrocarbons under high pressures.

The subject of "Low and Medium Temperature Carbonization and Retortable Oil-Yielding Materials" has been treated in considerable detail by W. H. Cadman. He first reviews the economic aspects of producing oil from coal, the Scottish Oil from the Coal Committee's Report and the results of various government research projects and the discussions on carbonization growing out of the 1936 International Chemical Engineering Congress. Then follow sections on plants and processes for producing oil from coal by low-temperature and medium-temperature carbonization. The Scottish shale industry is reviewed and a discussion of the coal, shale, and peat resources available for oil production in various parts of the world follows.

A section on "Petroleum Literature" by Winifred S. E. Clarke, briefly reviews the more pretentious books, monographs, bulletins and reports from various sources, and presents a classified list of 125 titles.

S. J. Astbury is the author of the section on "Petroleum Statistics." Tables are presented giving, in brief fashion, the principal statistics of crude petroleum, natural gas, asphalt, and oil-shale production, international trade in petroleum products, output of refined products in the United States, and the petroleum trade in Great Britain.

A comprehensive name and subject index concludes the volume.

From the standpoint of most American technologists, the book will seem somewhat out of balance in the amount of space and emphasis given to refining and to petroleum industry products and their utilization, in comparison

with the small emphasis given to the producing phase of the industry. Less space is devoted to the sections on "Geology," "Production," and "Drilling" than their importance in the field of petroleum technology and the volume of material published in these fields would justify. On the other hand, some relatively unimportant fields of technology are given more space than they deserve. However, probably no two individuals would agree on the relative amount of space that should be devoted in such a volume as this, to the different divisions.

One would not expect to find illustrations in a book of this type, but the eight included in the form of full-page lithographs, mostly photographs of refining plants, are excellent and lend variety and character. From the standpoint of composition, typography, binding, and craft workmanship, the volume will be found a pleasing addition to any library. Indeed, for the price charged, the book may be regarded as under-priced in terms of current prices on technical books.

LESTER C. UREN

UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA
October 4, 1937

RECENT PUBLICATIONS

ARGENTINA

*"Observaciones Estratigraficas en el Norte Argentina," (Stratigraphic Notes in Northern Argentina), by Otto Schlagintwest. *Bol. Inform. Petrol.* (Buenos Aires), No. 152 (April, 1937). 52 pp., 54 photographs. Reprint.

ARKANSAS

Arkansas Geological Survey Information Circular 11, "List of Arkansas Water Wells," compiled under the direction of George C. Branner. Information on 2,141 water wells in Arkansas, data to June 30, 1937. Maps of 75 counties. 142 pages, 23 plates, 2 tables. Price, $2.45.

COLORADO

*"Algae and Algal Limestone from the Oligocene of South Park, Colorado," by J. Harlan Johnson. *Bull. Geol. Soc. America* (New York), Vol. 48, No. 9 (September 1, 1937), pp. 1227–36; 2 pls.; 1 fig.

GENERAL

*"The Present State of Our Knowledge on the Origin of Petroleum," by C. D. Nenitzescu. *Jour. Inst. Petrol. Tech.* (London), Vol. 23, No. 166 (August, 1937), pp. 469–82.

*"A propos de l'emploi de l'avion dans la géologie" (Use of Aviation in Geology), by S. Zuber. *Rev. Pétrolifère* (Paris), No. 749 (September 3, 1937), pp. 1253–54.

*"Mineral Composition of Mississippi River Sands," by R. Dana Russell. *Bull. Geol. Soc. America* (New York), Vol. 48, No. 9 (September 1, 1937), pp. 1307–48; 1 pl., 2 figs.

*" 'Salt' Domes Related to Mississippi Submarine Trough," by Francis P. Shepard. *Ibid.*, pp. 1349–62; 6 figs.

*"Carbon Dioxide Accumulations in Geologic Structures," by J. Charles

Miller. *Amer. Inst. Min. Met. Eng. Tech. Pub. 841* (September, 1937). 28 pp., 5 figs.

*"Structural Behavior of Igneous Rocks," by Robert Balk. *Geol. Soc. America Mem. 5* (New York, July, 1937). 177 pp., 24 pls., 38 figs. 6.5×10 inches. Cloth.

GEOPHYSICS

"Geophysical Studies, 1932–1936," edited by C. A. Heiland, Dart Wantland, and R. F. Aldredge. *Colorado School of Mines Quarterly 32* (1), January, 1937 (October). 257 pp., 130 figs. 7×9 inches. Fourth of a series of geophysical publications edited at the School of Mines. The first of the series, "Geophysical Prospecting," an elementary introduction, giving statistical data and the application of geophysics in oil and mining exploration, is still selling, and meeting a practical demand. Subsequent issues have dealt with more specific research problems. The present publication contains nine special papers, representing all four of the major geophysical methods: seismic, gravitational, magnetic, and electrical. The book may be ordered from Association headquarters, Box 979, Tulsa, Oklahoma. Price, postpaid, $2.00.

*"Bibliography of Seismology," Vol. 12, No. 14 (April-June, 1937), by Ernest A. Hodgson. *Publications of the Dominion Observatory* (Ottawa, 1937). Items 3479–3565, pp. 289–99.

*"The Correlation Method of Seismographing for Oil," by Sylvain J. Pirson. *Oil Weekly* (Houston), Vol. 87, No. 2 (September 20, 1937), pp. 24–44.

MISSISSIPPI

*"Mississippi Oil and Gas Development," by Henry N. Toler. *Oil and Gas Jour.* (Tulsa), Vol. 36, No. 18 (September 16, 1937), pp. 55–57, 276; 6 maps.

MONTANA

*"The Fort Union of the Crazy Mountain Field, Montana, and Its Mammalian Fauna," by George Gaylord Simpson. *U. S. Nat. Mus. Bull. 169* (1937). 287 pp., 80 figs., 10 pls.

NEW YORK

*"Notes on a Core-Sample from the Atlantic Ocean Bottom Southeast of New York City," by J. A. Cushman, L. G. Henbest, and K. E. Lohman. *Bull. Geol. Soc. America* (New York), Vol. 48, No. 9 (September 1, 1937), pp. 1297–1306; 1 pl.

NORTH AND SOUTH CAROLINA

*"The Carolina Bays," by Gerald R. McCarthy. *Bull. Geol. Soc. America* (New York), Vol. 48, No. 9 (September 1, 1937), pp. 1211–26; 9 figs.

PENNSYLVANIA

*"Tully Limestone and Fauna in Pennsylvania," by Bradford Willard. *Bull. Geol. Soc. America* (New York), Vol. 48, No. 9 (September 1, 1937), pp. 1237–56; 2 pls.; 2 figs.

TEXAS

*"Geology and Economic Significance of Hastings Field, Brazoria County, Texas," by M. T. Halbouty. *World Petroleum* (New York, September, 1937), pp. 36–51; 26 illus.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 11 (NOVEMBER, 1937), PP. 1506-1508

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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TWENTY-THIRD ANNUAL MEETING, NEW ORLEANS, MARCH 16–18, 1938

The twenty-third annual meeting of the Association will be held at the Roosevelt Hotel, New Orleans, Louisiana, on March 16, 17, and 18, 1938. The Executive Committee of the Association met at Shreveport, September 11, 1937, and outlined plans for a timely program and a large attendance. R. A. Steinmayer, of Tulane University, is general chairman of convention arrangements and C. L. Moody is chairman of the technical program committee. A group of authoritative papers has been promised to review geological information particularly in Louisiana, South Arkansas, and the region east of the Mississippi River including Georgia and Florida.

The convention committees are as follows.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 11 (NOVEMBER, 1937), PP. 1509-1512

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

W. H. COREY has left the employ of the Standard Oil Company of California to accept foreign work with the Shell affiliated Caribbean Petroleum Company in Venezuela. He is accompanied to Venezuela by his family. His address is Apartado 19, Maracaibo, Venezuela, S. A.

CHARLES N. GOULD may be addressed at Box 5, Santa Fe, New Mexico.

WILLIAM A. NEWTON was awarded the Eric Knight Jordon Fellowship in Geology for 1937–38 at Stanford University, California.

The United States Bureau of Mines Petroleum Experiment Station at Bartlesville, Oklahoma, was dedicated, October 19, 1937.

The Houston Geological Society elected the following officers at the annual meeting, October 7: JOHN C. MILLER, president, The Texas Company; DAVID PERRY OLCOTT, vice-president, Humble Oil and Refining company; and LON D. CARTWRIGHT, JR., secretary-treasurer, Skelly Oil Company.

E. O. MARKHAM of the Carter Oil Company, Tulsa, was married to Miss Kathryn Wade, October 2.

The North Texas Geological Society held its first fall meeting on October 7. R. B. MCCULLAR, district sales manager for the Lane-Wells Company, Oklahoma City, spoke on the Gun-Perforator. Equipment and models were exhibited and the talk was illustrated with motion pictures.

The Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, held its regular meeting, October 18, at the Auditorium Hotel. "Geophysical Prospecting for Water" was discussed by C. A. HEILAND.

The Servicio Tecnico de Mineria y Geologia of Caracas, Venezuela, has founded a School of Geology which will be known as the "Instituto de Geologia."

H. L. GRILEY, land man for the Sun Oil Company, has been transferred from Tulsa, Oklahoma, to Mattoon, Illinois, to establish a new district office.

H. N. SEEVERS resigned from the Atlantic Refining Company, Corpus Christi, Texas, October 15, to go with the Shasta Oil Company. He will be in charge of the company's operations in south Texas.

The East Texas Geological Society, Tyler, Texas, elected the following officers at its first fall meeting recently: president, R. B. MITCHELL, Stanolind Oil and Gas Company; vice-president, R. L. JONES, Cities Service Oil Company; secretary-treasurer, E. A. MURCHISON, Humble Oil and Refining Company.

J. S. HUDNALL, of the firm of Hudnall and Pirtle, Tyler, Texas, was recently appointed a member of the Texas State Board of Registration for Professional Engineers.

ROY L. GINTER, consulting chemist, Tulsa, is the author of a paper, "Influence of Connate Water on Estimation of Oil Reserves" in the October 7 issue of the *Oil and Gas Journal*.

J. ELMER THOMAS spoke before the Houston Geological Society, October 14, on "A Report of the Seventeenth International Geological Congress and Petroleum Excursion, Held at Moscow."

LUTHER H. WHITE, Tulsa, Oklahoma, has resigned as chief geologist of the Sunray Oil Company to take a similar post with the Deep Rock Oil Corporation.

The following officers of the Shreveport Geological Society were recently elected for the coming year: president, B. W. BLANPIED, Gulf Refining Company; vice-president, E. B. HUTSON, Standard Oil Company of Louisiana; secretary-treasurer, J. D. AIMER, Arkansas Louisiana Gas Company.

P. E. FITZGERALD, research geologist for Dowell, Incorporated, Tulsa, spoke before the Oklahoma City Geological Society, October 11, on "Some Recent Developments in Acidizing."

JOHN W. CLARK, geologist with Magnolia Petroleum Company, has been transferred from Tyler to Dallas, Texas.

EDWARD W. RUMSEY has changed his address from Garden City, Kansas, to Shell Petroleum Corporation, 314 Rule Building, Amarillo, Texas.

The Shawnee Geological Society, Shawnee, Oklahoma, recently elected the following officers: president, A. M. MEYER, Atlantic Refining Company; vice-president, V. G. HILL, Stanolind Oil and Gas Company; secretary-treasurer, J. LAWRENCE MUIR, Amerada Petroleum Corporation.

JOHN C. MAHER, geologist with the Shell Petroleum Corporation, has changed his address from Tulsa to Wichita, Kansas.

HAROLD E. VOIGHT, formerly with the Skelly Oil Company, is now with the Shasta Oil Company, Midland, Texas.

OSCAR E. WALTON, geologist for the Atlantic Refining Company in Shreveport, has been transferred to the Corpus Christi, Texas, office as district geologist.

CLARENCE P. DUNBAR, formerly consulting geologist, Houston, Texas, is now working on special problems in the Research Department of the Department of Commerce and Industry, State Capitol, Baton Rouge, Louisiana.

The fall meeting of the Society of Exploration Geophysicists will be held at the Rice Hotel, Houston, Texas, November 19 and 20. There will be a joint luncheon with the Houston Geological Society on November 19, and a banquet the evening of November 20.

T. A. BENDRAT, of Beckley, West Virginia, has been engaged by the Caracas Petroleum Corporation as petroleum geologist and engineer for service in Venezuela. He sailed on the steamer *Caracas*, November 10.

W. R. CANADA and Mrs. Canada announce the birth of a daughter, Barbara Ann, October 29. Canada is with the Stanolind Oil and Gas Company at Lake Charles, Louisiana.

MALVIN G. HOFFMAN, geologist with the Midco Oil Corporation, Tulsa, spoke, October 18, on "Origin of the Earth," and ROBERT H. DOTT, director of the Oklahoma Geological Survey, Norman, spoke on "Something besides Oil," November 1, before the Tulsa Geological Society.

J. M. KIRBY, of The California Company, spoke before the Rocky Mountain Association of Petroleum Geologists at Denver, November 1, on the subject, "Geology of the Sacramento Valley Region."

JOSEPH A. TAFF, has retired from active service as consulting geologist of the Tide Water Associated Oil Company, Associated Division, 79 New Montgomery Street, San Francisco, California. His retirement closes a career of 28 years as chief geologist and consulting geologist, engaged in oil-land surveys and development in the Pacific region for the Southern Pacific Company and its owned and affiliated Pacific and Associated Oil Companies. His home address is 628 Cowper Street, Palo Alto, California.

W. TAPPOLET, geologist with the Dutch Shell in Mexico, visited in the United States the early part of November and then left for several months vacation at his home in Switzerland where his address is 56 Raemi Strasse, Zürich 7.

The North Texas Geological Society, Wichita Falls, has elected the following officers: president, A. W. WEEKS, Shell Petroleum Corporation; vice-president, TOM F. PETTY, Humble Oil and Refining Company; secretary-treasurer, P. E. M. PURCELL, Shell Petroleum Corporation.

W. ARMSTRONG PRICE, consulting geologist of Corpus Christi, spoke before the Houston Geological Society, the latter part of October, on "A Comparison of Gulf and Appalachian Geosynclines."

H. N. SEEVERS has resigned as district geologist for the Atlantic Refining Company at Corpus Christi, Texas, to become manager for the Shasta Oil Company.

O. E. WALTON, geologist with the Atlantic Refining Company at Shreveport, Louisiana, has succeeded H. N. SEEVERS at Corpus Christi.

L. F. MCCOLLUM, manager of explorations, Carter Oil Company, Tulsa, and F. W. FLOYD, manager of production, have been promoted to vice-presidencies in the company.

H. B. FUQUA, president of the A.A.P.G., spoke on Association affairs at the Houston Geological Society meeting in October, and at the South Texas Geological Society meeting, November 5–6.

IRA H. CRAM, secretary-treasurer of the A.A.P.G., spoke before the Tulsa Geological Society, October 28, on Association activities, particularly about the mid-year meeting at Pittsburgh, Pennsylvania, October 14–16.

Photograph taken at a technical session of The American Association of Petroleum Geologists, mid-year meeting, in the Urban Room of the William Penn Hotel, Pittsburgh, Pennsylvania, October 15, 1937.

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1st Vice-President - - - - - E. H. Hunt
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University of Colorado
Secretary-Treasurer - - - J. Harlan Johnson
Box 336, Colorado School of Mines, Golden, Colo.

Luncheon meetings, first and third Mondays of each month, 6:15 P.M., Auditorium Hotel.

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Regular Meetings: 7:30 P.M., Allis Hotel, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

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Vice-President - - - - - - E. B. Hutson
Standard Oil Company of Louisiana
Secretary-Treasurer - - - - J. D. Aimer
Arkansas-Louisiana Gas Company

Meets the first Friday of every month, Civil Courts Room, Caddo Parish Court House. Luncheon every Friday noon, Caddo Hotel.

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LAKE CHARLES, LOUISIANA

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Vice-President - - - - - H. V. Tygrett
Atlantic Production Company
Secretary - - - - - - - W. R. Canada
Stanolind Oil and Gas Company
Treasurer - - - - - - - Baker Hoskins
Shell Petroleum Corporation

Meetings: First Monday at noon (12:00) and third Monday at 7:00 P.M. at Majestic Hotel. Visiting geologists are welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - Ed I. Thompson
Phillips Petroleum Company

Meetings: First Tuesday of each month, from October to May, inclusive, at 7:30 P.M., Dornick Hills Country Club.

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OKLAHOMA CITY, OKLAHOMA

President - - - - - - - Leland W. Jones
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Coline Oil Company
Secretary-Treasurer - - - - H. L. Crockett
Colcord Building

Meetings: Second Monday, each month, 8:00 P.M., Commerce Exchange Building. Luncheons: Every Monday, 12:15 P.M., Commerce Exchange Building.

OKLAHOMA

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SHAWNEE, OKLAHOMA

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Secretary-Treasurer - - - J. Lawrence Muir
Amerada Petroleum Corporation

Meets the fourth Monday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

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Skelly Oil Company

Meetings: Second and fourth Wednesdays, each month, from October to May, inclusive, at 8:00 P.M.

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McBirney Building

Editor - - - - - - - Clyde G. Strachan
Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., fourth floor, Tulsa Building. Luncheons: Every Thursday, fourth floor, Tulsa Building.

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Texas Seaboard Oil Company

Meetings: Regular luncheons, first Monday of each month, 12:15 noon, Petroleum Club. Special night meetings by announcement.

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Secretary-Treasurer - - - - - Robert L. Jones
Empire Gas and Fuel Company

Meetings: Monthly and by call.

Luncheons: Every Friday, Cameron's Cafeteria.

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FORT WORTH, TEXAS

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Fort Worth National Bank Building

Vice-President - - - - - - A. L. Ackers
Stanolind Oil and Gas Company

Secretary-Treasurer - - - - - M. E. Upson
Gulf Oil Corporation

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

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HOUSTON, TEXAS

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Secretary-Treasurer - - Lon D. Cartwright, Jr.
Skelly Oil Company

Regular meetings, every Thursday at noon (12:15) at the Houston Club. Frequent special meetings called by the executive committee. For any particulars pertaining to meetings call the secretary.

TEXAS

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Shell Petroleum Corporation

Luncheons and evening programs will be announced.

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Magnolia Petroleum Company, San Antonio

Executive Committee - - - Adolph Dovre and C. C. Miller

Meetings: Third Friday of each month at 8 P.M. at the Petroleum Club. Luncheons every Monday noon at Petroleum Club, Alamo National Building, San Antonio, and at Plaza Hotel, Corpus Christi.

WEST TEXAS GEOLOGICAL SOCIETY

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Meetings will be announced

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Editor - - - - - - - M. M. Slotnick
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Independent Exploration Company, Houston, Texas
2011 Esperson Building

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Second National Bank Building
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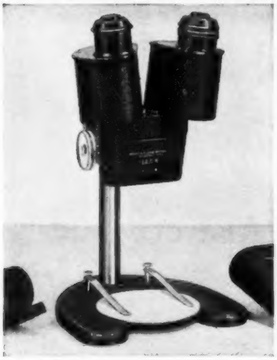
Secretary-Treasurer - - - Charles Brewer, Jr.
Godfrey L. Cabot, Inc., Box 348

Meetings: Second Monday, each month, at 6:30 P.M., Ruffner Hotel.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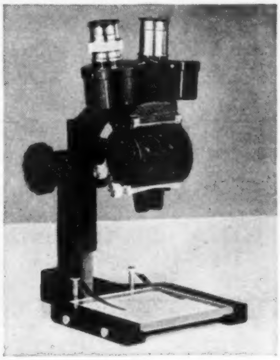
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